# NAVAL POSTGRADUATE SCHOOL
## MONTEREY, CALIFORNIA

# THESIS

METHODS FOR DETERMINING PERFORMANCE EXPECTATIONS AND OPTIMAL NO BUILD TIMES OF FIELDED JET ENGINES

by
Mark E. Mlikan
June 1996

Thesis Advisor: W. Max Woods

Thesis
M6555

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# METHODS FOR DETERMINING PERFORMANCE EXPECTATIONS AND OPTIMAL NO BUILD TIMES OF FIELDED JET ENGINES

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## ABSTRACT

This thesis investigates methods for determining fielded jet engine performance goals. Data exported from the Naval Aviation Logistics Data Analysis (NALDA) data base was fitted by a Weibull distribution to obtain the engine probability density function, cumulative density function, mean time between failure, failure rate, and conditional reliabilities. The thesis applies the results of the data analysis by using a commercial software package, Mathcad, to find the solution to an optimizing equation for average maintenance cost per hour of engine critical component operation. The solution yields optimum no build times given the component's Hard Time, ratios of several inspection/repair cost factors, and properties of the failure time probability distributions of the engine and component. The goal is to economize resources by inspecting life limited components when they are available after having accumulated a predetermined number of operating hours. The procedures developed can be used for any aircraft engine or any mechanical component with data that can be fitted to a Weibull distribution and with maintenance cost ratios that fit the model presented herein.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| $\theta$ | Theta - Weibull Distribution Scale Parameter |
| $\beta$ | Beta - Weibull Distribution Shape Parameter |
| A/C | Aircraft |
| CDF | Cumulative Distribution Function |
| CFBF | Cannibalization Followed By Failure |
| CNFBF | Cannibalization Not Followed By Failure |
| FHSN | Flight Hour Since New |
| FHSR | Flight Hour Since Repair |
| HPT | High Pressure Turbine |
| HT | Hard Time |
| IMA | Intermediate Maintenance Activity |
| MTBF | Mean Time Between Failure |
| MTTF | Mean Time To Failure |
| NADEP | Naval Aviation Depot |
| NALDA | Naval Aviation Logistics Data Analysis |
| NBT | No Build Time |
| P/REASON | Previous Reason for Removal |
| PDF | Probability Density Function |
| RCM | Reliability Centered Maintenance |
| RHS | Right Hand Side |
| REA-REM | Reason for Removal |
| REM-UIC | Removal Unit Identification Code |
| R(t) | Reliability at time t (Probability of surviving first t hours) |

| | |
|---|---|
| SERNO | Serial Number |
| SI | Significant Item |
| SSC | Status Star Code |
| STD DEV | Standard Deviation |
| T | Operating Time to Failure Since Last Repair of a Randomly Selected Engine |
| t | Hours Accumulated on Randomly Selected Engine Since Last Failure |
| $T_o$ | Critical Component Hard Inspection Time |
| $t_o$ | Component Optimal No Build Time |

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# I. INTRODUCTION

## A. BACKGROUND

### 1. Reliability Centered Maintenance

Until the late 1960s, the traditional maintenance approach for aircraft engines in both the commercial airline industry and military was to perform maintenance on a scheduled overhaul basis. However, research proved that engine reliability was not significantly improved by scheduled overhauls after a predetermined time period. As a result, a new maintenance approach called Reliability Centered Maintenance, or RCM, was developed based on reliability analysis. RCM, by formal definition, is the application of a disciplined logic or methodology to identify preventative maintenance tasks in order to realize the inherent reliability of a piece of equipment with the minimum expenditure of resources. Because it is a disciplined process, there are clearly definable steps to be followed when performing RCM. [Ref 1]

#### *a. Significant Items*

The first step in the RCM process for aircraft engines is to determine the functionally significant items. These are items whose failure could directly or indirectly affect safety of flight, result in severe damage or equipment loss, or have a significant economic impact. The list of significant items in an engine is a well-defined group that changes little except for the introduction of major new technologies. Significant Items are subjected to a Failure Modes, Effects, and Criticality Analysis (FMECA), which looks at the manner or mode in which the item might fail, the impact of the item's failure, and the

impact of the failure mode on the operation of the engine. From this analysis, a preventative maintenance program is developed for the engine. [Ref 2]

### *b. Hard Inspection Times*

The RCM analysis also identifies preventative maintenance tasks (basic servicing, inspection, test, calibration, and inspection) and task frequency. One specific process task is called Hard Time (HT) task. HT tasks relate to items with life limits that must be removed for inspection at the end of an expired operating period. [Ref 2]

### *c. Life Limited Components*

Major engine subassemblies, such as the compressor section, have indentured components with individually designated life limits. When these life limited components reach a predetermined number of operating hours they are removed for inspection and are either reconditioned and returned to service or scrapped. These items are also commonly referred to as "critical components" or "high-time components. Critical or high time components are items which must be removed for inspection after reaching a designated accumulated number of operating hours. HT differs from on-condition inspection in that on-condition inspections are performed on items for a specific cause other than operating hours. [Ref 2]

### *d. No Build Times*

When an engine has been removed from an aircraft for repair it follows that a decision should be made, because the engine is available, as to whether or not to inspect high time components which themselves are not the cause of the engine failure. The smallest predetermined operating time accumulated on a non-failed critical component when the decision is made to inspect it at the same time its mother engine is under repair is called

its No Build Time, or NBT. The goal is to economize resources by inspecting life limited components while they are readily available. One of the purposes of this thesis is to present a methodology for computing optimum NBT of a critical component given its HT, ratios of several inspection/repair cost factors, and properties of the failure time probability distributions of the engine and the critical component.

## B. REVIEW OF PREVIOUS RESEARCH

This thesis is a continuation of work previously conducted by LT Michael R. Caudill and LT John A. Malsbury in the area of performance goal setting for fielded jet engines. Their research included parametric and non-parametric statistical analysis of engine removal data for the TF-34 engine over a five year period using the NALDA data base. Probability density functions, cumulative density functions, mean time between failures, failure rates, and conditional reliabilies for the engine were obtained for a number of different data filters. In particular, various subsets of the data base were fitted by a Weibull distribution to allow development of closed form expressions for the probability distributions of the time between failure. These functions can be used for more advanced research in the area of setting inspection times and no build times.

## C. RESEARCH QUESTIONS

The overall guiding questions for this thesis are:

- What is the effect on engine MTTF and R(t) if residual life data is included in the Weibull analysis of failure population?
- Do the engines chosen for cannibalization have a characteristic that is unlike the engines that are not chosen for cannibalization?

- Can a method be established to determine cost effective no build times relative to hard inspection times for critical components of an aircraft engine?

- If a method can be established to determine optimum no build times, are the no build times currently in use for the TF-34 engine realistic? If not, what should they be?

## D. METHODOLOGY FOR NO BUILD TIMES

A mathematical model to calculate no build times was developed by Professor W. M. Woods and is used herein. In using the model, engine Weibull parameters were estimated using values calculated from actual data analysis, and component Weibull parameters values were assigned.

## E. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The scope of the research of this thesis was limited to the TF-34 engine, however, the logic and methodology used in determining optimal no build times can be used for any engine, or any mechanical component with data that can be fitted to a Weibull distribution and maintenance cost ratios similar to those used in the model presented herein.

This thesis uses predetermined parameter values for the probability distribution of the engine, assigned parameters values for the probability distribution of the components, a wide range of maintenance cost ratios, and component hard inspection times similar to those being used.

## F. THESIS ORGANIZATION

This thesis is divided into five chapters including the Chapter I introduction. Chapter II is further statistical analysis of the engine failure data. Chapter III is an explanation of the optimal equation for NBT. Chapter IV presents a sensitivity analysis of the Mathcad software package and a sensitivity analysis of the optimum NBT equation. Finally, Chapter V presents a summary, conclusions and recommendations.

# II. FURTHER STATISTICAL ANALYSIS OF ENGINE FAILURE DATA

## A. INCLUSION OF RESIDUAL LIFE DATA

Caudill [Ref 3] filtered the five year data base and obtained 723 operating times between engine failures. Various subsets of these failure times were used in both non-parametric and parametric analysis to compute the engine mean time between failure (MTBF), probability density function, cumulative density function, failure rate, and conditional reliabilities. The purpose of this section is to determine the effect on the engine performance parameters if residual life data is included along with the operating times between failures. The filtered subset of failure times that had the zero failure times removed is used in this analysis. Of the 723 operating times between failures, 39 were zeros resulting in 684 true failure times.

The failure times data base was screened for engines which had operating time accumulated after their last failure. If the last recorded failure removal was followed by a non-failure removal such as an inspection, cannibalization, or directed removal the operating time on the engine after the last failure was calculated using the engine age at the respective time of removal. The following procedure was used to determine these residual operating times:

Step 1: Sort the entire NALDA data base by engine serial number and isolate each different engine serial number.

Step 2: Sort each series of engine serial numbers by flight hour since new (FHSN) in ascending order to get a chronological history of the engines with failure removals.

Step 3: For each serial number that had a non-failure removal after its last failure, subtract the FHSN at the time of last failure from FHSN at time of non-failure removal.

Appendix A presents the data base of the results of this procedure. There were 106 residual life times obtained. Appendix B presents indexed failure times and indexed residual life times used in further analysis.

The same equations and procedures used by Caudill were used in this thesis to fit a Weibull distribution to the failure times plus residual operating times data base. The Weibull distribution statistical functions (less zero failure times subset) are presented in Table 2-1. The engine Weibull parameters $\beta$ and $\theta$ increased from 1.3092 to 1.6093 and 558.609 to 687.617, respectively, with the residual life data included. Figures 2-1, 2-2, 2-3, and 2-4 present graphs of these functions compared with failure time (less zeros) only as computed by Caudill.

Table 2-2 presents conditional probabilities for selected values of T, operating time to failure since last repair of a randomly selected engine, and t, hours accumulated on the randomly selected engine since last failure. Values for T are given across the top row and values for t are given in the far left column. For example, in Table 2-2, for T = 300 and t = 50, the probability that an engine will operate without failure to time 500 hours, given it has accumulated 50 hours, is 78.82%. This conditional probability is denoted by R(300|50). These conditional probabilities are presented graphically in Figure 2-5 where T is represented by the different curves, t is the x-axis value, and the conditional probability is the y-axis value. For the same example, R(300|50) is determined from the top set of curves in Figure 2-5. The y-axis off the topmost curve (300 Hrs) at t = 50 shows a probability slightly below 0.80 corresponding with the value from Table 2-2 of 78.72%.

The failure removal data was modified to include all failure times, less zero failure times, less random 50% of failure times less than 100, and less random 80% of failure times less than 100. PDF functions for the modified data bases are presented in Figure 2-6. The graphs indicate that as low value failure times are removed from the data base, both parameter $\beta$ and $\theta$ increase significantly.

| Failure Times t | Weibull PDF f(t) | Weibull CDF F(t) | Failure Rate h(t) | Reliability R(t) |
|---|---|---|---|---|
| 0 | 0.0000 | 0.0000 | 0.0000 | 1.0000 |
| 50 | 0.0005 | 0.0146 | 0.0005 | 0.9854 |
| 100 | 0.0007 | 0.0439 | 0.0007 | 0.9561 |
| 150 | 0.0008 | 0.0827 | 0.0009 | 0.9173 |
| 200 | 0.0010 | 0.1281 | 0.0011 | 0.8719 |
| 250 | 0.0010 | 0.1782 | 0.0013 | 0.8218 |
| 300 | 0.0011 | 0.2314 | 0.0014 | 0.7686 |
| 350 | 0.0011 | 0.2863 | 0.0016 | 0.7137 |
| 400 | 0.0011 | 0.3418 | 0.0017 | 0.6582 |
| 450 | 0.0011 | 0.3968 | 0.0018 | 0.6032 |
| 500 | 0.0011 | 0.4506 | 0.0019 | 0.5494 |
| 550 | 0.0010 | 0.5025 | 0.0020 | 0.4975 |
| 600 | 0.0010 | 0.5520 | 0.0022 | 0.4480 |
| 650 | 0.0009 | 0.5989 | 0.0023 | 0.4011 |
| 700 | 0.0008 | 0.6427 | 0.0024 | 0.3573 |
| 750 | 0.0008 | 0.6834 | 0.0025 | 0.3166 |
| 800 | 0.0007 | 0.7208 | 0.0026 | 0.2792 |
| 850 | 0.0007 | 0.7550 | 0.0027 | 0.2450 |
| 900 | 0.0006 | 0.7861 | 0.0028 | 0.2139 |
| 950 | 0.0005 | 0.8141 | 0.0028 | 0.1859 |
| 1000 | 0.0005 | 0.8391 | 0.0029 | 0.1609 |
| 1050 | 0.0004 | 0.8614 | 0.0030 | 0.1386 |
| 1100 | 0.0004 | 0.8812 | 0.0031 | 0.1188 |
| 1150 | 0.0003 | 0.8985 | 0.0032 | 0.1015 |
| 1200 | 0.0003 | 0.9137 | 0.0033 | 0.0863 |
| 1250 | 0.0002 | 0.9269 | 0.0034 | 0.0731 |
| 1300 | 0.0002 | 0.9384 | 0.0034 | 0.0616 |
| 1350 | 0.0002 | 0.9483 | 0.0035 | 0.0517 |
| 1400 | 0.0002 | 0.9567 | 0.0036 | 0.0433 |
| 1450 | 0.0001 | 0.9639 | 0.0037 | 0.0361 |
| 1500 | 0.0001 | 0.9701 | 0.0038 | 0.0299 |
| 1550 | 0.0001 | 0.9752 | 0.0038 | 0.0248 |
| 1600 | 0.0001 | 0.9796 | 0.0039 | 0.0204 |
| 1650 | 0.0001 | 0.9833 | 0.0040 | 0.0167 |
| 1700 | 0.0001 | 0.9863 | 0.0041 | 0.0137 |
| 1750 | 0.0000 | 0.9889 | 0.0041 | 0.0111 |
| 1800 | 0.0000 | 0.9909 | 0.0042 | 0.0091 |
| 1850 | 0.0000 | 0.9927 | 0.0043 | 0.0073 |
| 1900 | 0.0000 | 0.9941 | 0.0043 | 0.0059 |
| 1950 | 0.0000 | 0.9953 | 0.0044 | 0.0047 |
| 2000 | 0.0000 | 0.9962 | 0.0045 | 0.0038 |

| | |
|---|---|
| **RECORDS** | **684** |
| TRIAL | 683.9999 |
| BETA | 1.6093 |
| THETA | 687.617 |
| MTBF | 613.650 |
| VARIANCE | 166231 |
| STD DEV | 407.714 |

| | Value |
|---|---|
| 1+1/BETA | 1.621 |
| 1+2/BETA | 2.243 |

| Gamma |
|---|
| 0.89243 |
| 1.14801 |

Table 2-1. Weibull Distribution Statistical Functions Data
(Failure times (less zeros) plus residual operating times)

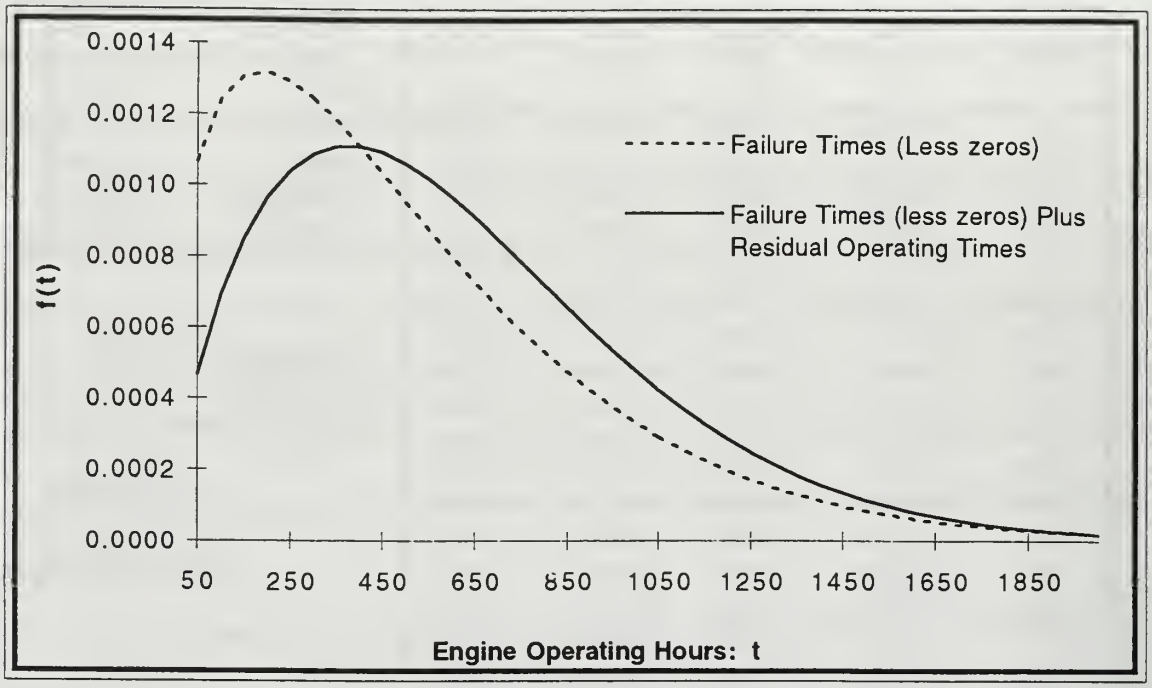



Figure 2-1. Weibull Distribution PDF Comparison

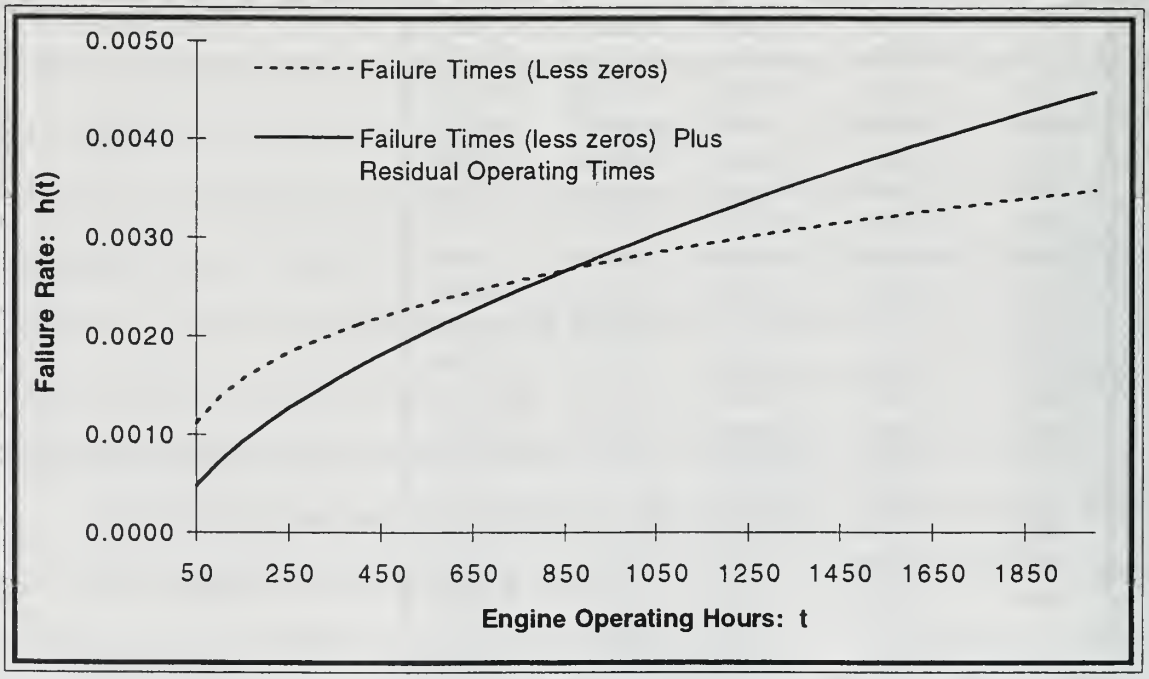



Figure 2-2. Weibull Distribution Failure Rate Comparison

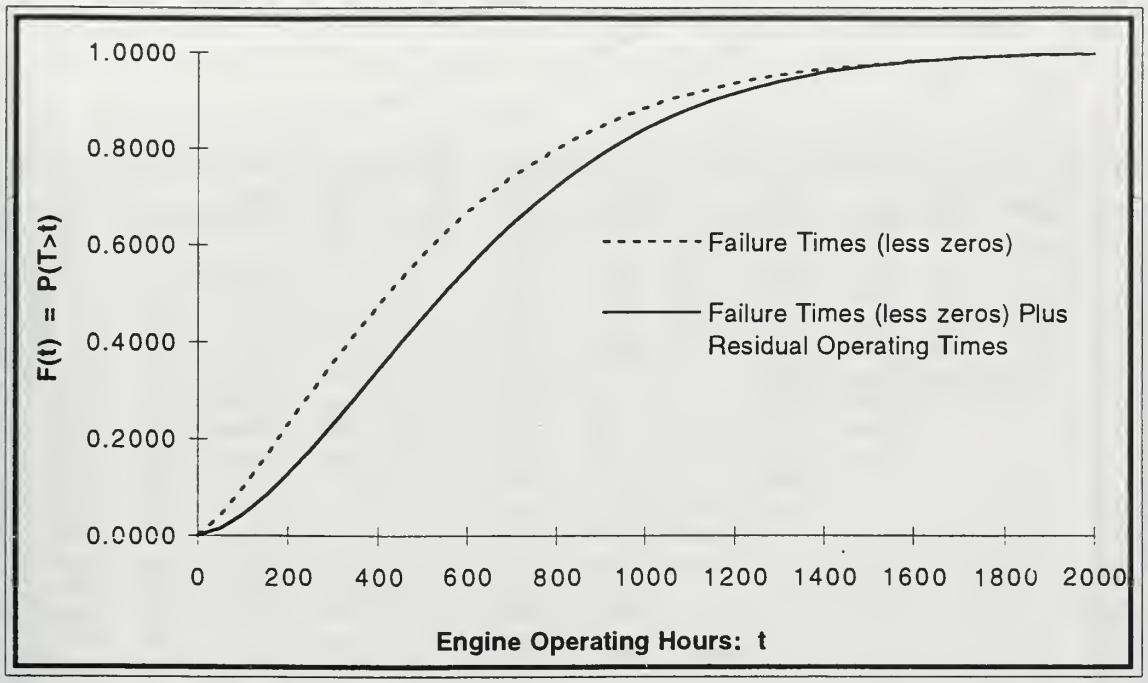



Figure 2-3. Weibull Distribution CDF Comparison

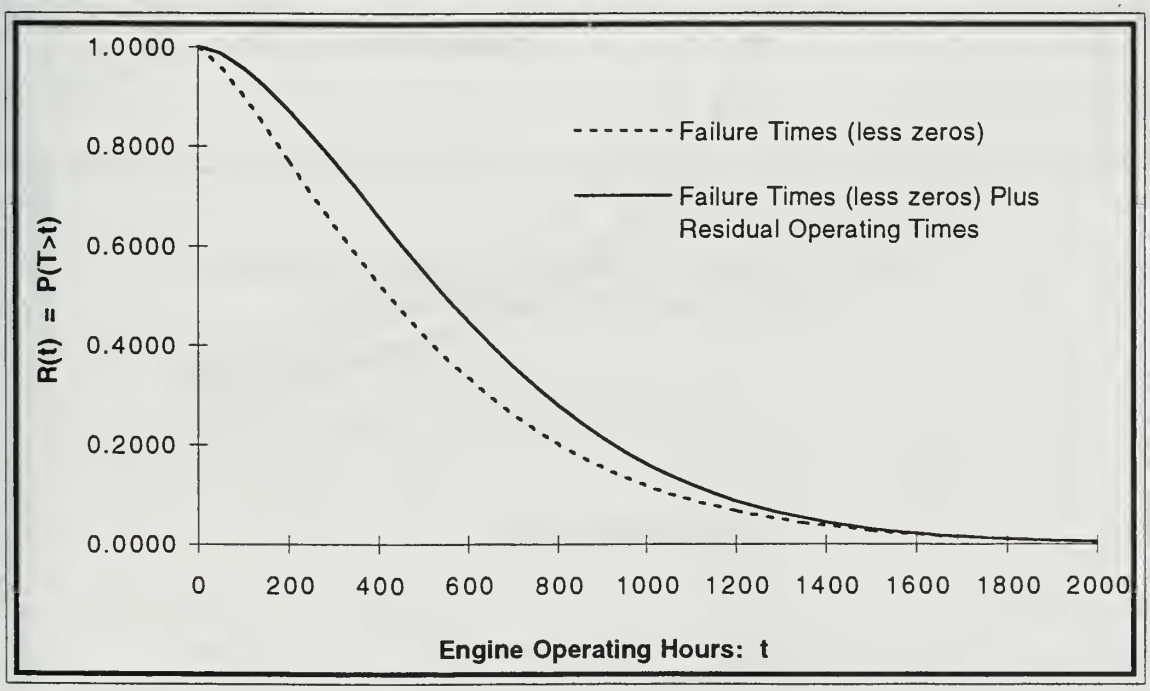
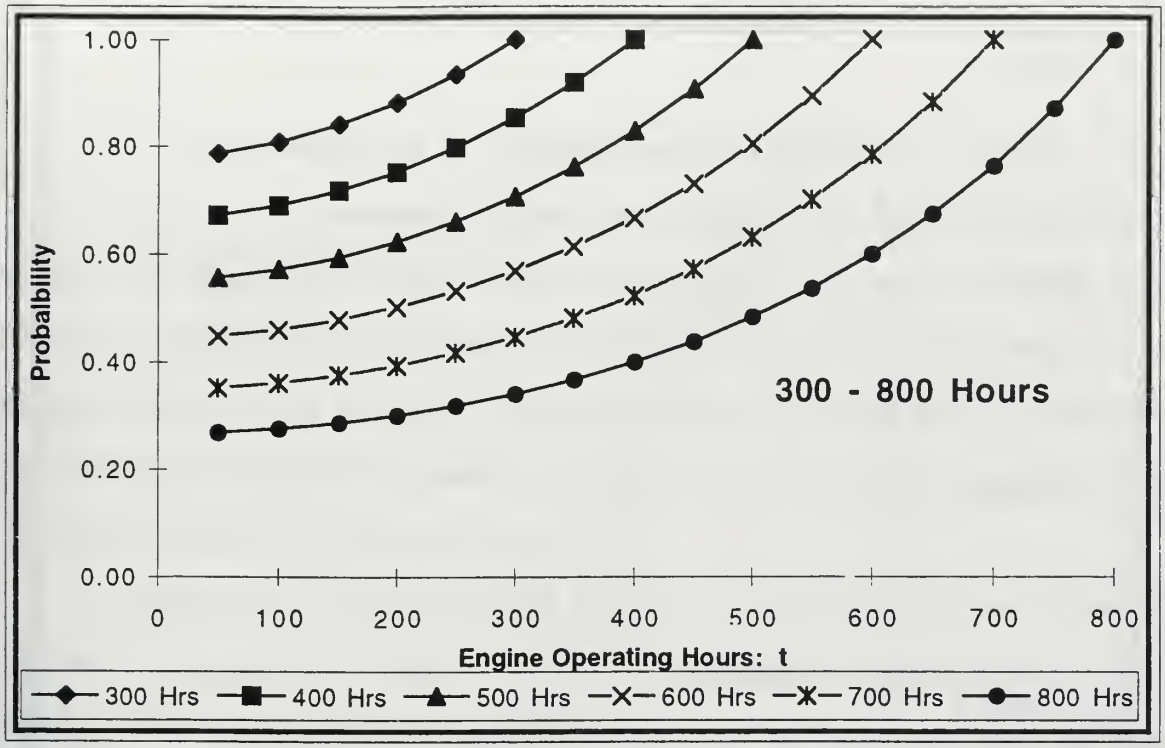



Figure 2-4. Weibull Distribution Reliability Comparison

| AHRR | 300 Hrs Prob | 400 Hrs Prob | 500 Hrs Prob | 600 Hrs Prob | 700 Hrs Prob | 800 Hrs Prob | 900 Hrs Prob | 1000 Hrs Prob | 1100 Hrs Prob | 1200 Hrs Prob | 1300 Hrs Prob | 1400 Hrs Prob | 1500 Hrs Prob |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 0.7872 | 0.6721 | 0.5568 | 0.4484 | 0.3516 | 0.2688 | 0.2005 | 0.1461 | 0.1040 | 0.0725 | 0.0494 | 0.0330 | 0.0215 |
| 100 | 0.8087 | 0.6905 | 0.5720 | 0.4607 | 0.3612 | 0.2761 | 0.2060 | 0.1501 | 0.1069 | 0.0744 | 0.0507 | 0.0339 | 0.0221 |
| 150 | 0.8405 | 0.7176 | 0.5945 | 0.4788 | 0.3754 | 0.2870 | 0.2141 | 0.1560 | 0.1111 | 0.0774 | 0.0527 | 0.0352 | 0.0230 |
| 200 | 0.8825 | 0.7535 | 0.6242 | 0.5027 | 0.3942 | 0.3013 | 0.2248 | 0.1638 | 0.1166 | 0.0812 | 0.0554 | 0.0370 | 0.0242 |
| 250 | 0.9353 | 0.7986 | 0.6616 | 0.5328 | 0.4178 | 0.3194 | 0.2382 | 0.1736 | 0.1236 | 0.0861 | 0.0587 | 0.0392 | 0.0256 |
| 300 | 1.0000 | 0.8538 | 0.7073 | 0.5696 | 0.4467 | 0.3414 | 0.2547 | 0.1856 | 0.1321 | 0.0920 | 0.0627 | 0.0419 | 0.0274 |
| 350 | | 0.9204 | 0.7625 | 0.6140 | 0.4815 | 0.3681 | 0.2746 | 0.2000 | 0.1424 | 0.0992 | 0.0676 | 0.0451 | 0.0295 |
| 400 | | 1.0000 | 0.8284 | 0.6671 | 0.5231 | 0.3999 | 0.2983 | 0.2173 | 0.1548 | 0.1078 | 0.0735 | 0.0490 | 0.0321 |
| 450 | | | 0.9069 | 0.7303 | 0.5727 | 0.4378 | 0.3265 | 0.2379 | 0.1694 | 0.1180 | 0.0804 | 0.0537 | 0.0351 |
| 500 | | | 1.0000 | 0.8053 | 0.6315 | 0.4827 | 0.3601 | 0.2624 | 0.1868 | 0.1301 | 0.0887 | 0.0592 | 0.0387 |
| 550 | | | | 0.8943 | 0.7013 | 0.5361 | 0.3999 | 0.2913 | 0.2075 | 0.1445 | 0.0985 | 0.0657 | 0.0430 |
| 600 | | | | 1.0000 | 0.7841 | 0.5994 | 0.4471 | 0.3258 | 0.2320 | 0.1616 | 0.1101 | 0.0735 | 0.0481 |
| 650 | | | | | 0.8826 | 0.6747 | 0.5033 | 0.3667 | 0.2611 | 0.1819 | 0.1240 | 0.0827 | 0.0541 |
| 700 | | | | | 1.0000 | 0.7644 | 0.5702 | 0.4154 | 0.2958 | 0.2061 | 0.1405 | 0.0937 | 0.0613 |
| 750 | | | | | | 0.8716 | 0.6502 | 0.4737 | 0.3373 | 0.2349 | 0.1601 | 0.1069 | 0.0699 |
| 800 | | | | | | 1.0000 | 0.7460 | 0.5435 | 0.3870 | 0.2696 | 0.1837 | 0.1226 | 0.0802 |
| 850 | | | | | | | 0.8611 | 0.6274 | 0.4468 | 0.3112 | 0.2121 | 0.1416 | 0.0925 |
| 900 | | | | | | | 1.0000 | 0.7286 | 0.5188 | 0.3614 | 0.2463 | 0.1644 | 0.1075 |
| 950 | | | | | | | | 0.8511 | 0.6061 | 0.4221 | 0.2877 | 0.1920 | 0.1256 |
| 1000 | | | | | | | | 1.0000 | 0.7121 | 0.4960 | 0.3381 | 0.2256 | 0.1475 |
| 1050 | | | | | | | | | 0.8415 | 0.5861 | 0.3995 | 0.2666 | 0.1743 |
| 1100 | | | | | | | | | 1.0000 | 0.6965 | 0.4747 | 0.3168 | 0.2072 |
| 1150 | | | | | | | | | | 0.8323 | 0.5673 | 0.3786 | 0.2475 |
| 1200 | | | | | | | | | | 1.0000 | 0.6816 | 0.4549 | 0.2974 |
| 1250 | | | | | | | | | | | 0.8234 | 0.5495 | 0.3593 |
| 1300 | | | | | | | | | | | 1.0000 | 0.6674 | 0.4363 |
| 1350 | | | | | | | | | | | | 0.8148 | 0.5327 |
| 1400 | | | | | | | | | | | | 1.0000 | 0.6538 |
| 1450 | | | | | | | | | | | | | 0.8065 |
| 1500 | | | | | | | | | | | | | 1.0000 |

Table 2-2. Weibull Distribution Conditional Probabilities
(Failure Times Plus Residual Life Data)



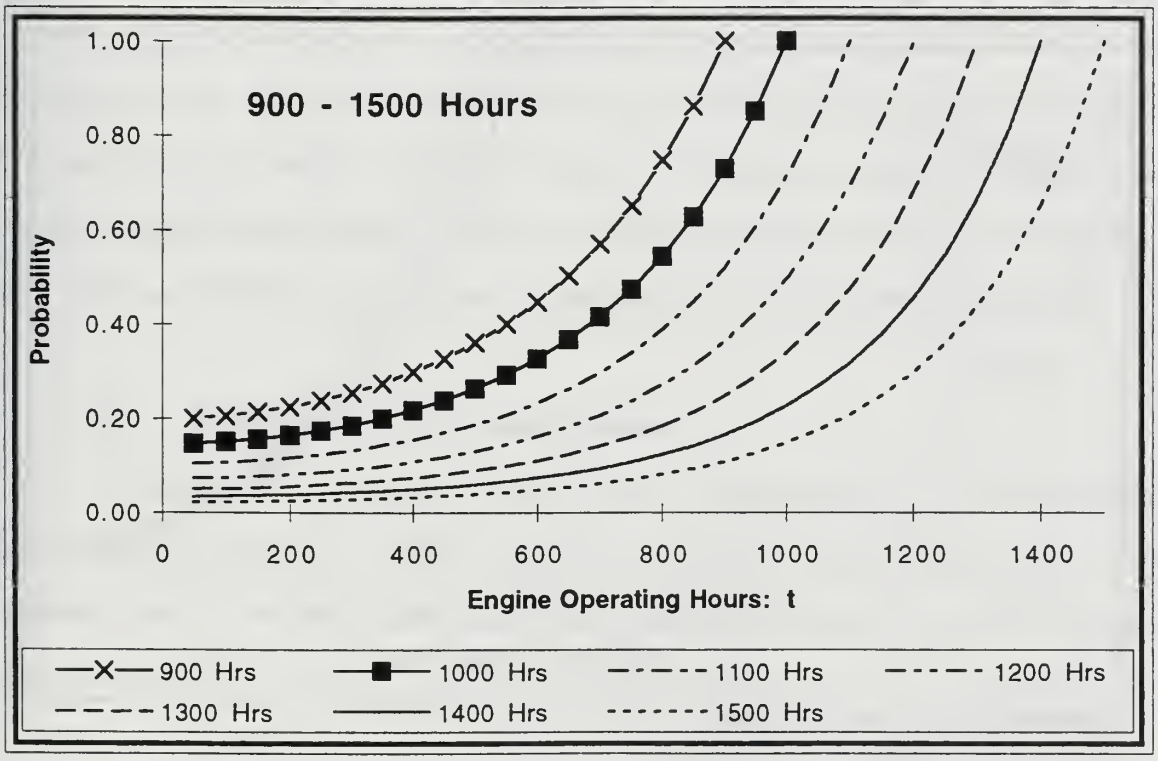




Figure 2-5. Conditional Probabilities With Residual Operating Times

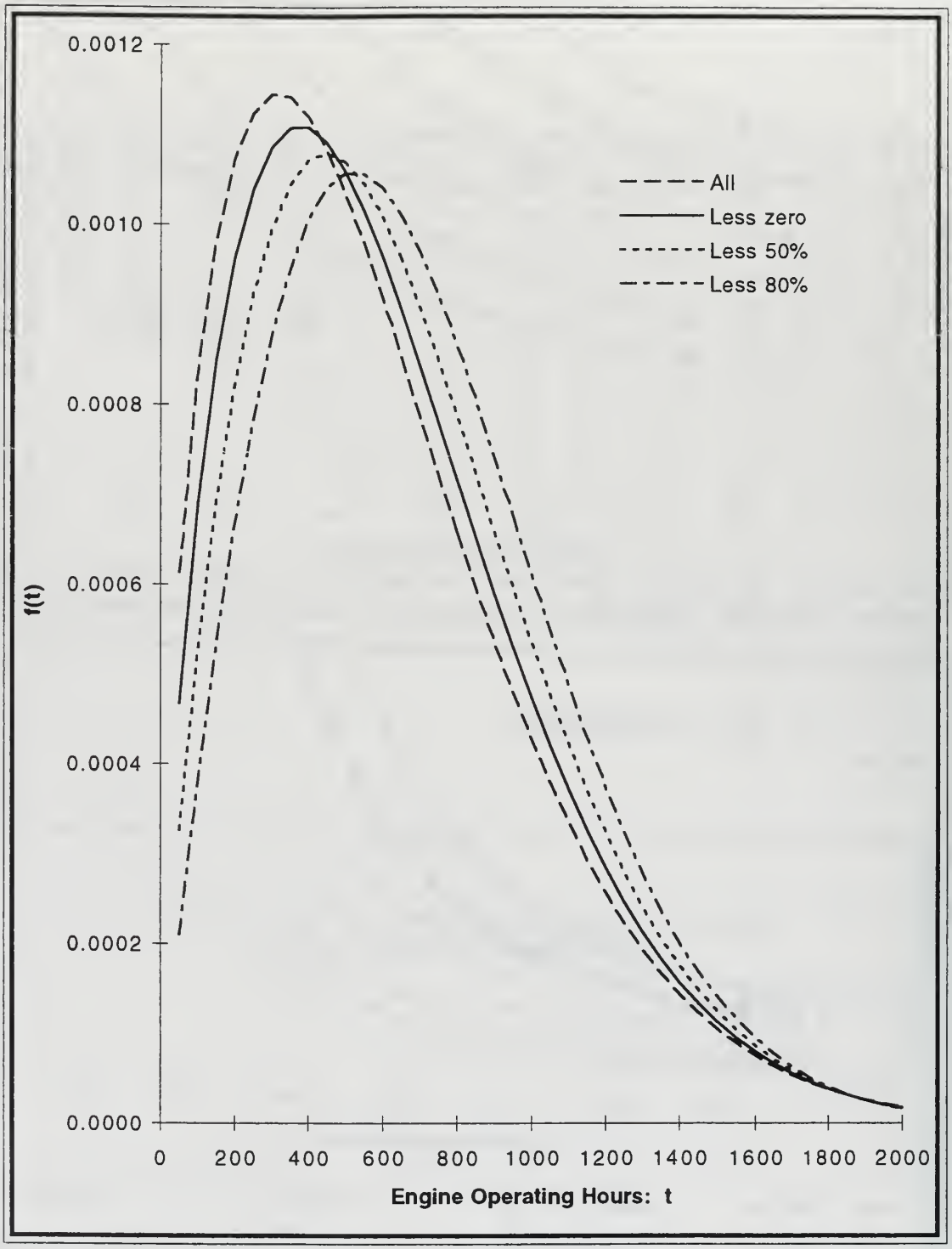



Figure 2-6. Weibull Distribution PDF Comparison

## B. AFFECTS OF CANNIBALIZATION ON MTBF

### 1. Characteristics of Cannibalizations Followed by Failure

Caudill observed a correlation between cannibalization actions and subsequent time to failure. Malsbury [Ref 4] further validated the correlation in an analysis by fiscal year. This section analyzes the data further to determine if there is any difference between two groups of cannibalization actions: (1) cannibalization actions that are directly followed by *failure* removal as presented by Caudill and Malsbury, and (2) cannibalization actions that are directly followed by *non-failure* removal.

A comparison of FHSR and FHSN, at the time of cannibalization, was performed for these two groups. There were a total of 554 cannibalization actions during FY90 - FY94. 171 of these cannibalization actions fall within the first group, i.e., the very next removal was for a failure reason. The remaining 383 cannibalization actions fall within the second group, i.e., the very next removal was for a non-failure reason. Table 2-3 presents the results of the comparison of these two groups. The comparison shows that there is no significant difference in terms of FHSN and FHSR for these two groups. This indicates that FHSN and FHSR are not taken into consideration when engines are cannibalized.

### 2. Failures Across Cannibalization

A comparison of failure times which crossed cannibalization (i.e., engines which were cannibalized between failure removals) and failure times which did not cross cannibalization (i.e., no cannibalization between the failure removals) was conducted to see the affect on MTBF. Table 2-4 shows that failure times which crossed cannibalization had a MTBF of 632 while failure times which did not cross cannibalization had a MTBF of 426. Caudill [Ref 3: p. 39] found that engines which crossed cannibalization had a MTTF after cannibalization of 247.

| Category | FY | No | Avg FHSN | Avg FHSR |
|---|---|---|---|---|
| Canns Directly Followed by Failure | 90 | 31 | 4252 | 436 |
| | 91 | 37 | 4224 | 314 |
| | 92 | 42 | 4733 | 425 |
| | 93 | 44 | 4541 | 384 |
| | 94 | 17 | 5021 | 450 |
| | | 171 | 4554 | 402 |
| Canns Not Directly Followed by Failure | 90 | 128 | 4146 | 498 |
| | 91 | 97 | 4536 | 556 |
| | 92 | 82 | 4817 | 453 |
| | 93 | 25 | 4978 | 519 |
| | 94 | 51 | 5469 | 407 |
| | | 383 | 4789 | 487 |
| Total Cannibalization Actions | | 554 | | |

Table 2-3. Comparison of CFBF and CNFBF

| Category | FY | No | MTBF |
|---|---|---|---|
| True Failures | 90 | 172 | 411 |
| | 91 | 148 | 507 |
| | 92 | 157 | 501 |
| | 93 | 121 | 489 |
| | 94 | 99 | 499 |
| | | 697 | 481 |
| Failures Across Cannibalization | 90 | 31 | 512 |
| | 91 | 37 | 561 |
| | 92 | 42 | 734 |
| | 93 | 44 | 686 |
| | 94 | 17 | 665 |
| | | 171 | 632 |
| Failures Without Cannibalization | 90 | 141 | 389 |
| | 91 | 111 | 497 |
| | 92 | 115 | 414 |
| | 93 | 77 | 375 |
| | 94 | 82 | 455 |
| | | 526 | 426 |

Table 2-4. Comparison of MTBF Across Cannibalization

# III. ESTABLISHING OPTIMAL NO BUILD TIMES

## A. OPTIMAL NO-BUILD TIME EQUATION

This chapter explains the equation for computing optimal no-build times relative to hard inspection times of critical components.

The equation uses the Weibull distribution to model the time to failure of an aircraft engine and also for the time to failure of a critical component. The Weibull probability density function is:

$$f(t) = \left(\frac{\beta}{\theta^{\beta}}\right) t^{\beta-1} e^{\left(\frac{t}{\theta}\right)^{\beta}} \tag{1}$$

The shape parameter, β, is a measure of the rate of wear out. The scale parameter, θ, is a measure of the mean time to failure. The failure rate function h(t), for the Weibull distribution is:

$$h(t) = \frac{\beta}{\theta^{\beta}} t^{\beta-1} \tag{2}$$

The true mean time to failure, MTTF, of the Weibull distribution is:

$$\text{MTTF} = \theta\Gamma\left(1 + \frac{1}{\beta}\right) \tag{3}$$

where $\Gamma(x)$ is the gamma function. If $\beta=1$, this density function is the exponential density. Analyses of the TF-34 engine NALDA data performed by Caudill and Malsbury indicates $1.2 < \beta < 1.5$. The value of β is almost certainly smaller for the critical components. The reliability function $R(t)=P(T>t)$ for this distribution is:

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}} \tag{4}$$

The conditional reliability function

$$R(t \mid x) = P(T > t \mid T > x), \quad t>x \text{ is}$$

$$R(t \mid x) = \frac{e^{-\left(\frac{t}{\theta}\right)^{\beta}}}{e^{-\left(\frac{x}{\theta}\right)^{\beta}}} = e^{-\left[\left(\frac{t}{\theta}\right)^{\beta}-\left(\frac{x}{\theta}\right)^{\beta}\right]} \tag{5}$$

When applying the Weibull distribution to component failure time in the optimum no-build time equation, the following notation is used:

$\theta = a$ and $\beta = c$ for the critical component

and

$\theta = b$ and $\beta = d$ for the engine.

The remaining parameters in the optimization equation are the following:

y = $T_o$: Hard inspection time of the critical component

u = $C_n$: Cost to perform a component hard inspection when the engine is already off the wing and being repaired due to some failure other than the critical component.

v = $C_i$: Cost to perform the hard inspection of the critical component when the engine is still operational; i.e., still on the wing. This cost will include the cost to remove the engine from the wing and break the engine down. This removal cost is not included in u.

w = $C_f$: Cost to inspect/repair/replace the critical component after it has failed.

x = $t_o$: Optimum no-build time for the component; i.e., if the operating time accumulated on the critical component when the engine has been removed from the wing for repair or whatever is greater than $t_o$, then the engine should not be rebuilt without inspecting/repairing/replacing the critical component.

The optimal no build time equation is:

$$\frac{u}{x} := u\int_0^{y-x} \frac{1}{t+x}\left(\frac{1}{b}\right)^{d}(d)(t)^{d-1}e^{-\left[\left(\frac{t}{b}\right)+\left(\frac{t+x}{a}\right)-\left(\frac{x}{a}\right)\right]}dt + \frac{v}{y}e^{-\left[\left(\frac{y-x}{b}\right)-\left(\frac{y}{a}\right)+\left(\frac{x}{a}\right)\right]} + w\int_x^{y}\frac{1}{t}\left(\frac{1}{a}\right)(c)(t)^{c-1}e^{-\left[\left(\frac{t}{a}\right)+\left(\frac{x}{a}\right)-\left(\frac{t-x}{b}\right)\right]}dt \tag{6}$$

In the optimizing equation, the left member, u/x, denotes the cost per unit hour to perform hard inspection/repair on the critical component if inspection is done now when the engine is already off the wing for some reason and has accumulated x operating hours. The right hand side (RHS) of the equation is the average cost per unit time to perform hard inspection/repair of the critical component, if we do not do the inspection now, when the engine is off the wing, but do it at any one of the three following opportunities:

a) When the engine fails at a future time, before the operating time on the critical component reaches its hard inspection time, y, is taken off the wing for repair, and the critical component has not failed (first term of the RHS).

b) When the operating time on the critical component has accumulated to the designated hard inspection time, y, and the engine has not failed since it has been reinstalled on the wing (second term of the RHS).

c) When the critical component has failed prior to its hard inspection time and the engine has not failed since last installation up to the time the critical component failed (third term of the RHS).

If it is decided to wait for another chance to do hard inspection when the engine has been removed again (for repair), the operating cost per unit time to do the hard inspection when the engine fails at t hours after reinstallation (operating time on component is x+t) is u/(t+x). To get the average cost per unit time this cost must be multiplied by the "probability" (density function) of engine failure at time t times the probability the component "lives" beyond x+t hours given it is "alive" at time x and integrated across all times between x and y; i.e., for $0 < t < (y - x)$. The time t in this integral is time on the engine after reinstallation and t+x is total time accumulated on the component.

The second term is the cost per operating hours, v/y, to do hard inspection when the engine is on the wing at the time y hours is accumulated on the component times the probability that the engine has not failed in the (y-x) hours after reinstallation times the probability the component lives beyond y hours given it was alive at x hours.

The third term is the cost per unit time, w/t, of doing hard inspection on the critical component when the component fails at its operating time t given it was alive at time x times the probability the engine lives (except for the component) beyond time t-x. This is an average cost per unit time. In this term, the variable t is time accumulated on the component (from birth or since last repair).

If a component has accumulated more than the optimal number of hours, x, when its parent engine is removed for repair, then it would be cost effective to inspect/repair/replace the component as well before reinstalling the engine. Therefore, x is the optimal no build time.

Figure 3-1 is a Mathcad printout presenting the solution for optimal NBT for one set of values for Cn, Ci, and Cf, and their ratios as well, while all other parameters are held constant. The symbol := is "defined as." The number x:= 200 at the top of the printout is an initializing value the software package needs to solve the equation. The values of u, v, w, (i.e. Cn, Ci, Cf) are 500, 750, 1000 respectfully which yield cost ratios of Ci/Cn = 1.5 and Cf/Cn = 2. The component has a MTTF (Weibull shape parameter), a, of approximately 4000 hours and a wear-out parameter, c, of 1.2. The engine has a MTTF (Weibull shape parameter), b, of approximately 500 hours and a wear-out parameter, d, of 1.3. The hard inspection time, y, is 1000 hours. The optimal value of x, i.e., the solution for x, is the value on the RHS of the g(a, b, c, d, u, v, w, y) term. In this case the optimal no-build time is 798 hours.

Note in the solution that one only need know the ratios Ci/Cn, Cf/Cn, and Cn and not the values of Ci and Cf to fine the optimal NBT x. That is, x depends on Cn, Ci/Cn, and Cf/Cn. This can be seen by dividing the equation through by u (i.e. Cn) in the optimizing equation.

Table 3-1 displays a summary of a Mathcad solution printout with the no build time solutions of 763 and 586 hours respectively for the same set of parameters values and cost ratio pairs of (2,4) and (4,10).

x:=200

given

$$\frac{u}{x} := u\int_0^{y-x} \frac{1}{t+x}\left(\frac{1}{b}\right)^d (d)(t)^{t-1} e^{-\left[\left(\frac{t}{b}\right)+\left(\frac{t+x}{a}\right)-\left(\frac{x}{a}\right)\right]} dt + \frac{v}{y} e^{-\left[\left(\frac{y-x}{b}\right)-\left(\frac{y}{a}\right)+\left(\frac{x}{a}\right)\right]} + w\int_x^y \frac{1}{t}\left(\frac{1}{a}\right) (c)(t)^{c-1} e^{-\left[\left(\frac{t}{a}\right)+\left(\frac{x}{a}\right)-\left(\frac{t-x}{b}\right)\right]} dt$$

g(a, b, c, d, u, v, w, y) := find (x)

u:= 500
v:= 750
w:= 1000
a:= 2000
c:= 1.2
b:= 500
d:= 1.3
y:= 1000

g(a, b, c, d, u, v, w, y) = 798

Figure 3-1. Mathcad Solution for Optimum NBT

| Cost ratio pair (u = 10,000) = | (2, 4) | (4, 10) |
|---|---|---|
| x:= | 200 | 200 |
| u:= | 10000 | 10000 |
| v:= | 20000 | 40000 |
| w:= | 40000 | 100000 |
| a:= | 4000 | 4000 |
| c:= | 1.2 | 1.2 |
| b:= | 500 | 500 |
| d:= | 1.3 | 1.3 |
| y:= | 1000 | 1000 |
| g(a, b, c, d, u, v, w, y) = | **763** | **586** |

Table 3-1. Mathcad printout summary

# IV. SENSITIVITY ANALYSIS OF SOLUTION METHOD AS A FUNCTION OF COST RATIOS

## A. MATHCAD PROCEDURES AND SENSITIVITY

### 1. Mathcad Solver Procedures

Mathcad is a windows based software package that combines the mathematical solution capabilities of an electronic spreadsheet with the equation editor capabilities of a word processor. This combination allows an equation to be typed into the program and solved as it actually appears. [Ref 5]

Mathcad has the capability to solve systems of equations and can be used to find optimizing solutions. In the case of the optimizing equation for NBT, as presented in equation (6) in Chapter III, code is entered into the Mathcad worksheet as depicted in Figure 3-1. Mathcad's solution value for x from the NBT equation appears on the RHS of the term g(a, b, c, d, u, v, w, y). The constants are engine/component parameters, maintenance cost ratios, and component hard times as previously defined in Chapter III. Changes in any of these constants will likely yield different solution values for x. Changing only u, v and w by a common multiple will not yield a different solution because their ratios remain unchanged.

### 2. Mathcad Solver Sensitivity

Before determining the effects of changes in any of the different parameters on the solution of the optimizing equation for NBT it was first necessary to determine the sensitivity of the Mathcad package itself. Using the Mathcad solver it was observed that different values of the cost ratio Cf/Cn had no effect on the solution given set values of

other parameters. Moreover, changing the values of cost inputs while holding cost ratios and other parameters constant resulted in different solutions values for x.

To determine the sensitivity of the Mathcad solver, solution values for x were obtained for three different cost ratio pairs with the other parameters being held constant. The Mathcad solution value for x was entered into the RHS of the optimizing equation which was defined simply as f(x). The input cost, u, was then divided by the solution for x and the result was compared to f(x). They should be equal. Table 4-1 compares the values of u/x and f(x) for the three cost ratio pairs. Because the values of u/x and f(x) are not equal, it was concluded that the solution for x given by the Mathcad command used in Figure 3-1 is not always the optimal value for x. This problem is due to round off error in the Mathcad solution method.

| u= 10,000 | Ci/Cn | Cf/Cn | x | u/x | f(x) |
|---|---|---|---|---|---|
| a = 2000 | 2 | 3 | 787 | 12.71 | 18.69 |
| b = 500 | 3 | 4 | 683 | 14.64 | 24.90 |
| c = 1.0 | 4 | 5 | 615 | 16.26 | 30.41 |
| d = 1.2 | | | | | |
| y = 1000 | | | | | |

Table 4-1. Mathcad Solver Solutions for "x" and Comparison of u/x and f(x)

## 3. Mathcad Graphical Solution Procedures

A graphical solution method using Mathcad was performed to resolve the round off error problem. The same input cost value, u, and the three cost ratio pairs were used to test this procedure. The following methodology was used to enter code into the Mathcad worksheet:

Step 1: Define values for the constants.

Step 2: Define a range for the variable x.

Step 2: Define the optimum NBT equation as f(x).

Step 3: Define u/x as g(x).

Step 4: Using the Mathcad graphing capabilities read the optimum solution for x as the intersection of the curves for f(x) and g(x).

Figure 4-1 is an example of a typical Mathcad graphical solution printout. In Figure 4-1 the optimum value, $x_o$, of x is 638 hours.

## 4. Mathcad Graphical Solution Sensitivity

As with the solver solution method, the graphical solution for x was entered into the RHS of the optimizing equation expressed as f(x) and compared to u/x. Table 4-2 presents this comparison for the same three scenarios. It shows that that u/x equals f(x) for the three cost ratio pairs.

| u= 10,000 | Ci/Cn | Cf/Cn | x | u/x | f(x) |
|---|---|---|---|---|---|
| a = 2000 | 2 | 3 | 484 | 20.66 | 20.68 |
| b = 500 | 3 | 4 | 340 | 29.41 | 29.45 |
| c = 1.0 | 4 | 5 | 257 | 38.91 | 38.92 |
| d = 1.2 | | | | | |
| y = 1000 | | | | | |

Table 4-2. Graphical Solutions for x and comparison of u/x and f(x)

Figure 4-2 presents a Mathcad graphical solution printout for value of x ranging from 100 to 1000. It is a macro-view showing the behavior of the two curves f(x) and

g(x). The curve for f(x) is the RHS of the optimal no build time equation. A point along the f(x) curve is the expected cost per flight hour if it is decided not to inspect the component while the mother engine is being repaired and wait for a chance to do so later. The curve g(x) represents u/x. A point on this curve is the actual cost per flight hour if the component is inspected when the mother engine is under repair and the component has accumulated x flight hours of operation.

Appendix C presents selected macro-view graphical solution printouts showing the behavior of the two curves. These curves can be used to determine reasonable ranges for the no build time around the optimal solution. Anywhere the two curves are relatively close to each other would yield a no build time approaching the optimal solution. For example, in the printout example on page 81 a reasonable range would be from x = 480 to x = 1000. This reasonable range for no build times can be used in conjunction with logistic support factors such as manpower and material availability, scheduling constraints, safety concerns and operational requirements to make intelligent maintenance decisions.

$u := 10000 \quad v := 15000 \quad w := 20000 \quad a := 2000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 600..700$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$

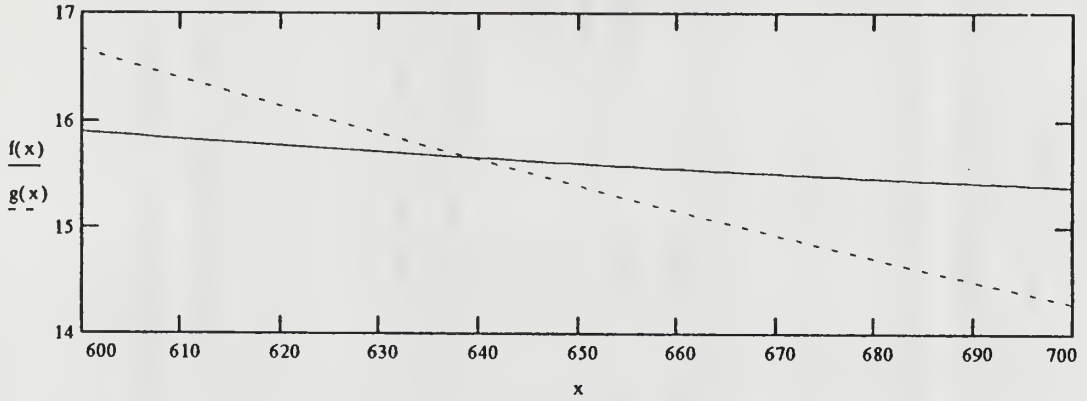



Figure 4-1. Mathcad Graphical Solution Printout

$u := 10000 \quad v := 15000 \quad w := 80000 \quad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$

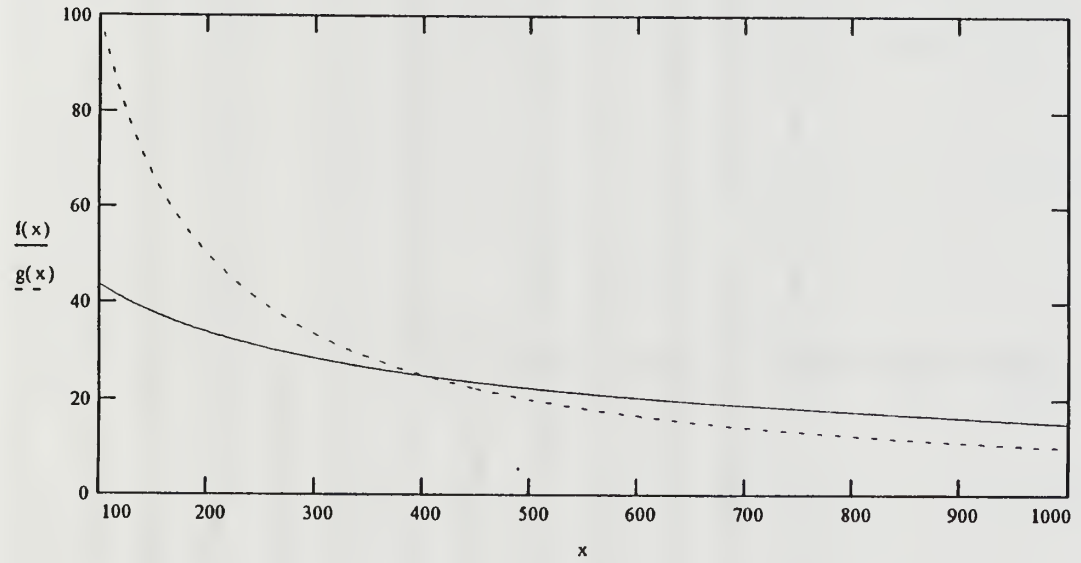



Figure 4-2. Mathcad Graphical Solution Printout for Range x = 100...1000

## B. OPTIMAL NO BUILD TIME EQUATION SENSITIVITY

The sensitivity of the optimal NBT equation to changes in the various parameters was determined using the graphical solution method. The equation takes into account three costs: Cn, Ci, and Cf. If the ratios of Ci/Cn and Cf/Cn are known then Ci and Cf can be determined from a given value of Cn and all three costs can then be entered into the equation. Different values of engine and component parameters as well as hard times can then be entered into different cost ratio scenarios.

An input value for u of 10,000 was used along with cost ratio assumptions of $v/u < w/u$ where $3 < w/u < 10$. Ranges for parameter values for the engine and component along with the component hard times used in the sensitivity analysis are presented in Table 4-3.

| Parameter: | Low | Middle | High |
|---|---|---|---|
| Theta Component (a) | 2000 | 4000 | 6000 |
| Beta Component (c) | 1.0 | 1.2 | 1.5 |
| Theta Engine (b) | 500 | 700 | 1000 |
| Beta Engine (d) | 1.2 | 1.5 | 2.0 |
| Component Hard Time (y) | 1000 | | 2000 |

Table 4-3. Sensitivity Analysis Parameter Range Values

The following systematic approach was used to determine the sensitivity of the optimum NBT equation to changes in the engine/component parameters and different component HT:

Step 1: Use lowest range value of each parameter for each cost ratio.

Step 2: Use middle range value of beta and theta component (a and c) with lowest range value of other parameters for each cost ratio.

Step 3: Use highest range value of beta and theta component (a and c) with lowest range value of other parameters for each cost ratio.

Step 4: Use middle range value of theta component (a) with lowest range value of all other parameters for each cost ratio.

Step 5: Use highest range value of theta component (a) with lowest range value of all other parameters for each cost ratio.

Step 6: Use middle range value of beta component (c) with lowest range value of all other parameters for each cost ratio.

Step 7: Use highest range value of beta component (c) with lowest range values of all other parameters for each cost ratio.

Step 8: Use middle range value of beta and theta engine (b and d) with lowest range value of other parameters for each cost ratio.

Step 9: Use highest range value of beta and theta engine (b and d) with lowest range value of other parameters for each cost ratio.

Step 10: Use middle range value of theta engine (c) with lowest range value of all other parameters for each cost ratio.

Step 11: Use highest range value of theta engine (c) with lowest range value of all other parameters for each cost ratio.

Step 12: Use middle range value of beta engine (d) with lowest range value of all other parameters for each cost ratio.

Step 13: Use high range value of beta engine (d) with lowest range value of all other parameters for each cost ratio.

Step 14: Repeat steps 1 through 13 for the component hard time (y) of 2000.

Following these steps yielded 26 different parameter/HT combinations. A tabulation of graphical solution values of x for each of the combinations is presented in Appendix D.

Figures 4-3, 4-4, and 4-5 present some graphical displays of the solutions for x for different cost ratio pairs and parameter values. Figure 4-3 displays curves for different values of Cf/Cn ratios while Ci/Cn is held constant at 1.1 and 1.5. Figures 4-4 and 4-5 shows how the solution for x changes relative to changes in each of the four individual

engine/component parameters for low cost ratio pairs of (1.1, 1.2) and (1.5, 2) and higher cost ratio pairs of (1.5, 6) and (2, 8). As shown in the displays the solution for optimum no build time is particularly sensitive to the value of the cost ratios.

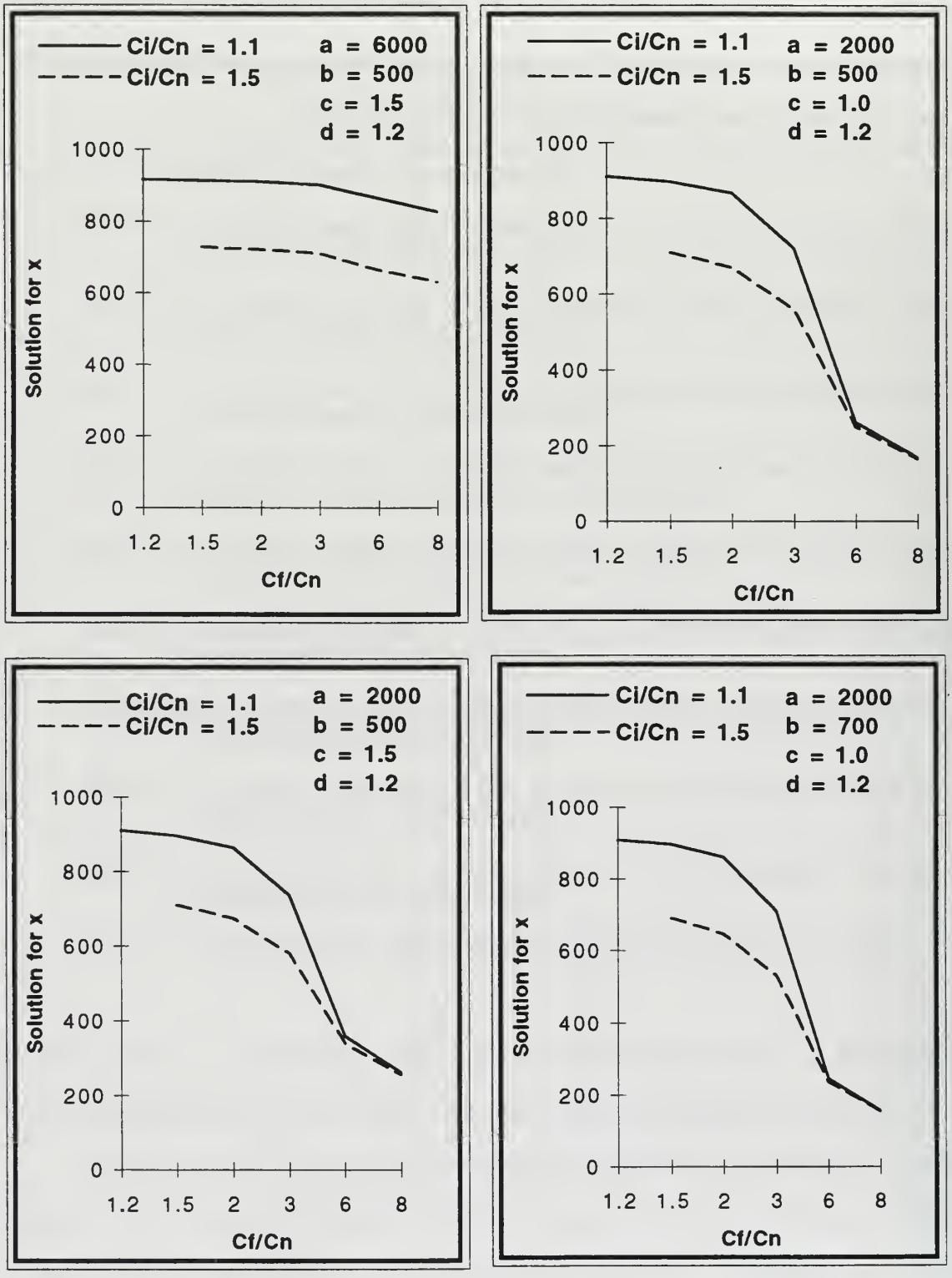



Figure 4-3. Solutions for Constant Parameter Values and Varying Cost Ratio Pairs

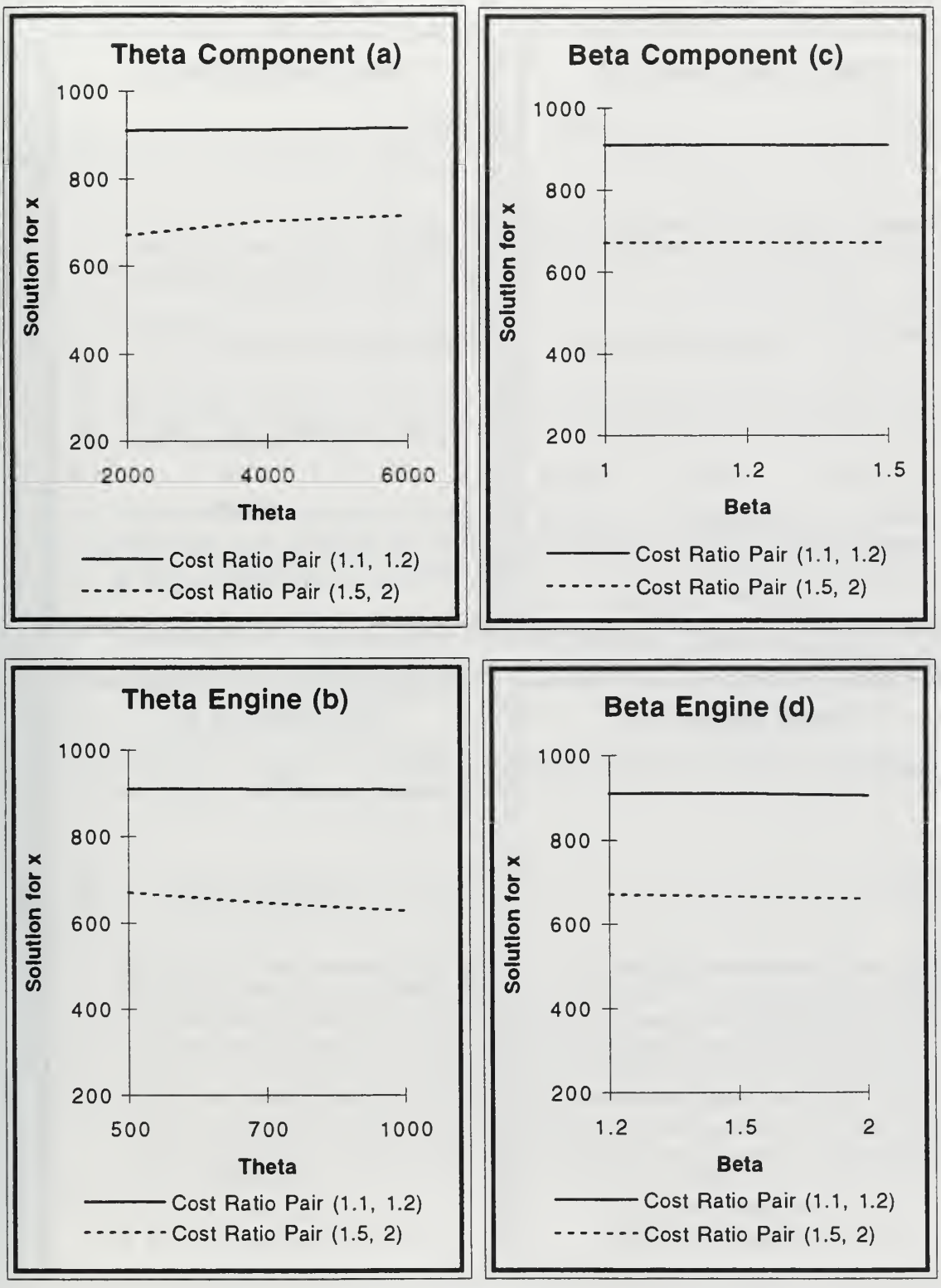



Figure 4-4. Solutions Values for "x" Relative to Changes in Weibull Parameters

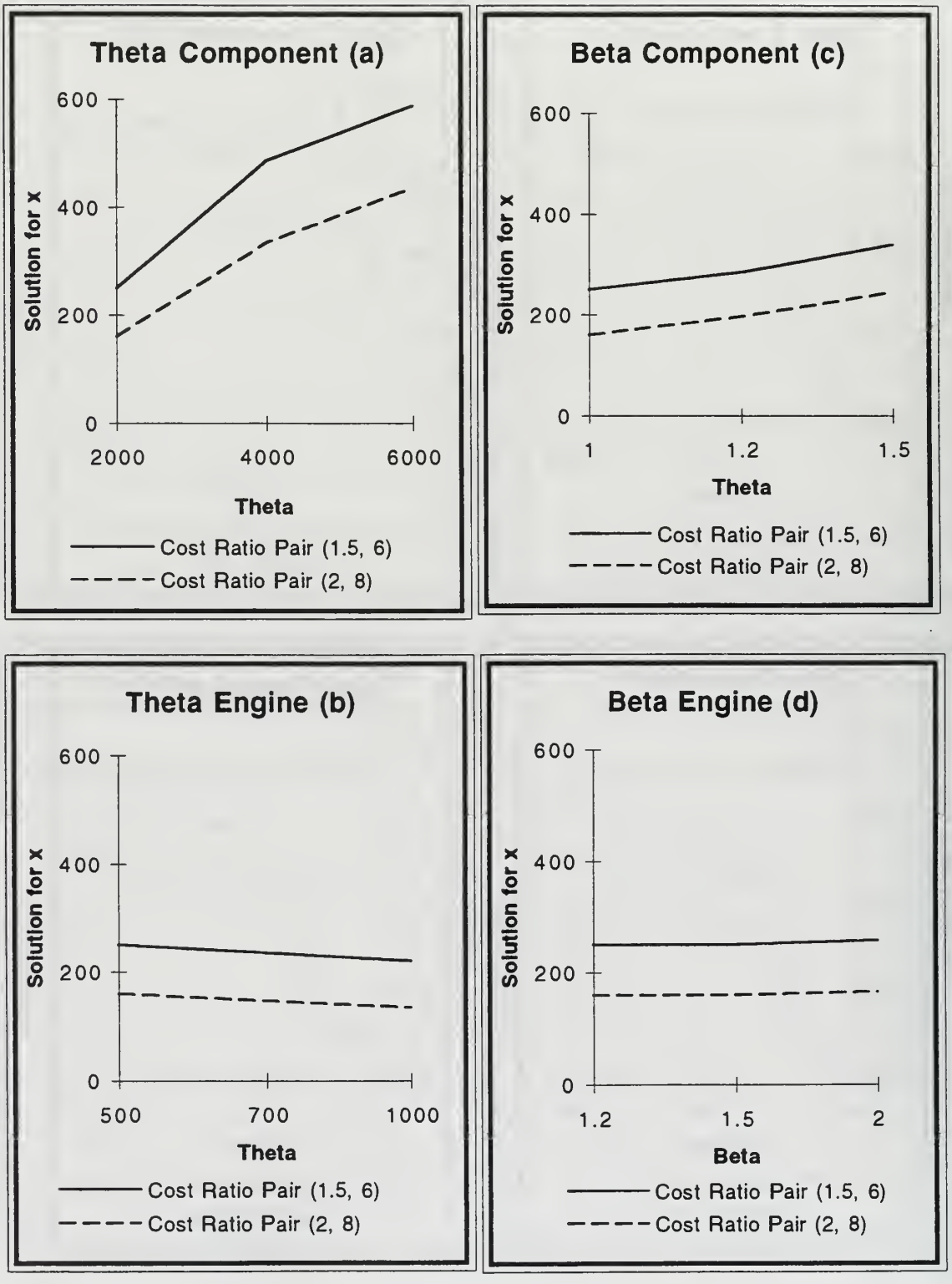



Figure 4-5. Solutions for x Relative to Changes in Weibull Parameters

# V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## A. SUMMARY

This thesis addressed the following topics:

- The inclusion of residual life data with the engine failure removal times to determine the affect on engine Weibull parameters and related statistical distribution functions for the TF-34.

- Some further analysis of the affect of cannibalization on MTBF.

- Discussion of engine component no built time relative to hard inspection time and maintenance costs.

- Explanation of optimal no build time equation and discussion of method to determine cost effective no build times relative to hard inspection times for critical components of an aircraft engine.

- Demonstration of commercially available software package (Mathcad) to solve for optimal no build times given maintenance cost ratios and engine and component Weibull parameters

- Sensitivity analysis of optimal no build time equation relative to maintenance cost ratios and Weibull parameters.

## B. CONCLUSIONS

- Inclusion of the residual life data in with the failure removal data had a significant impact on the statistical measures of the TF-34 engine. This means the reliability of the TF-34 is greater than previously determined using failure data only and residual data should be included in this type of analysis. For the data base subset analyzed in this thesis the Weibull parameter $\beta$ increased from 1.3092 to 1.6093, and the Weibull parameter $\theta$ increased from 559 to 688. These upgraded parameter figures resulted in positive changes to the engine probability density function, failure rate, reliability, and conditional probabilities and engine MTBF.

- It can be concluded that even though cannibalization is random, the high chances of failure following cannibalization actions are relevant and significant. From the further analysis of the affect of cannibalization on MTBF it can be shown that engines chosen for cannibalization are chosen randomly. There is no characteristic distinguishing engines that are not operation at the next removal following cannibalization from engines that are operational at the next removal following cannibalization. However, 30 percent of the cannibalization actions in the data base were engines that subsequently were not operation at the time of next removal.

- Although the mean time to first failure following cannibalization actions is significantly lower than the failure population MTBF, the population of failure times which crossed over cannibalization actions had a higher MTBF than engines with failure times which did not cross over cannibalization actions. This indicated that at the time of cannibalization, some type of corrective maintenance is performed on the engine even though the engine fails in a relatively short period of time following cannibalization

- A valid method was established to determine cost effective no build times relative to hard inspection times for critical components. Using the optimal no build time and the commercial software package Mathcad, optimal times to inspect components can be determined for any combination of maintenance cost ratios pairs, engine and component Weibull parameters, and component hard time.

- The graphical solution procedure is the superior method when determining optimal no build times using Mathcad. The solution yielded by the Mathcad solver is insufficiently accurate for solving our optimization equation when used at the default parameter settings of Mathcad. Graphical solutions also give more insight into the cost implications associated with changing no build time.

- It is important to have accurate cost ratios when using the model. Maintenance cost ratios, as addressed in this thesis, have a significant impact on the solution for optimal no build time. Practical values for these ratios, given $Ci/Cn < Cf/Cn$, are $1.1 < Ci/Cn < 3$ and $1.2 < Cf/Cn < 5$.

- Engine and component Weibull parameters do not have as great an impact on the solution for optimal no build times as do maintenance cost ratios. The parameters that the solution is most sensitive to are $\theta$ and $\beta$ for the component.

- The model presented in this thesis can be used to determine more accurate no build times than the ones currently in use for the TF-34 engine using appropriate maintenance cost ratios - whatever they will be as a fallout of the way inspection is done and what the specific component is.

## C. RECOMMENDATIONS

- Continue to use all available data to refine reliability measures for the TF-34 engine in order to get the most realistic statistical function as possible. Reliability measures determined in this thesis were from a five year data base from FY 90 to FY 94. The NALDA data base should be queried for records beyond this period to get more engine failure times and residual operating times for use in the analysis.

- Conduct a review of cannibalization policies for the TF-34 engine to see if there is a way to reduce the number of cannibalization actions. The shear number of cannibalization actions during the five year period covered in this thesis and the fact that 30 percent of the engines which are cannibalized are non-operational at the time of their next removal warrants a study. By reducing the number of cannibalization actions it follows that the number of subsequent failure removals could be reduced thereby resulting in higher readiness rates and lower man-hour expenditures.

- Analyze fleet TF-34 maintenance procedures to see how many of the low failure times may be the result of improper maintenance procedures rather than the inherent reliability of the engine/components. If it is determined that training can be improved then some funding directed towards component improvement can perhaps be directed towards training program improvement.

- Make the model for determining optimal no build times available to the fleet in a user friendly form. Fleet users can then query the NALDA data base for historical removal data on engines and components and subject the data to the same analysis as was performed in this thesis. The analysis can be expanded to all engines in the Navy inventory.

- Optimize resource expenditures in engine maintenance by determining what the actual maintenance costs and maintenance cost ratios are for the TF-34 engine and compare them to the ones calculated in this thesis. This is an area for further study.

- Make historical engine data available to students at NPS by establishing a satellite NALDA data base terminal such as the ones available at major air stations. The data base can be queried for data for use in the thesis process. Much good can be achieved using actual field data and statistical methods taught at NPS.

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# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

## A. CONTENTS OF APPENDIX A

Appendix A is the data base sort used to calculate residual operating times. The data base lists the chronological failure removal history of each engine serial number along with the last non-failure removal if applicable. The last non-failure removal is printed in bold type and indicates an engine that has residual operating time following last failure. At that time the engine was removed for a reason other than failure. The serial numbers with no bolded entry have no record of a non-failure removal following last failure. There are 106 engines with residual operating times.

The residual operating time was calculated by taking the flight hours since new at the time of last removal (non-failure) minus the flight hours since new at the time of the previous failure removal. For example, the first entry, serial number 0201021, shows an engine that was removed for failure (reason for removal code 7K) at 3359 operating hours since new. It was subsequently removed for inspection (reason for removal code 7C) at 3893 flight hours since new. The residual operating time is then 3893 - 3359 = 534 hours as indicated.

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0201021 | 3359 | 33 | 7K | 3Q | 8910 |
| *** 0201021** | **3893** | **534** | **7C** | **1Z** | **9201** |
| * 0201022 | 3076 | 301 | 3Q | 2N | 8910 |
| * 0201022 | 3115 | 39 | 8P | 3Q | 9008 |
| *** 0201022** | **3549** | **434** | **3W** | **3Q** | **9110** |
| * 0201101 | 4805 | 685 | 4P | 5G | 9002 |
| * 0201101 | 5295 | 490 | 1Z | 6F | 9109 |
| * 0201102 | 5148 | 310 | 4M | 5G | 9003 |
| * 0201102 | 5236 | 88 | 1Z | 4M | 9106 |
| * 0201102 | 6068 | 832 | 3T | 7C | 9406 |
| * 0201103 | 5428 | 1018 | 3D | 1Z | 9012 |
| * 0201103 | 5431 | 3 | 5Q | 3D | 9108 |
| * 0201104 | 5166 | 293 | 3A | 1Z | 9004 |
| * 0201104 | 5327 | 161 | 6N | 3W | 9108 |
| * 0201104 | 6416 | 1089 | 3R | 6J | 9409 |
| * 0201106 | 5833 | 994 | 2N | 5Q | 9010 |
| *** 0201106** | **6419** | **586** | **7C** | **3T** | **9407** |
| * 0201108 | 5485 | 465 | 5Q | 7C | 9310 |
| * 0201109 | 3606 | 211 | 5C | 5G | 9002 |
| * 0201110 | 5431 | 1030 | 8B | 7C | 9106 |
| * 0201110 | 5652 | 221 | 3T | 6Q | 9209 |
| * 0201110 | 5670 | 18 | 3T | 5Q | 9312 |
| *** 0201110** | **5696** | **26** | **3W** | **3T** | **9401** |
| * 0201111 | 5539 | 271 | 7A | 7C | 9107 |
| * 0201111 | 5895 | 356 | 1B | 7A | 9209 |
| * 0201111 | 6136 | 241 | 3R | 1B | 9312 |
| * 0201112 | 5189 | 927 | 3P | 5G | 9007 |
| * 0201112 | 5804 | 615 | 3Q | 3M | 9211 |
| * 0201113 | 5313 | 262 | 1Z | 3Q | 9006 |
| * 0201113 | 5335 | 22 | 2N | 1Z | 9103 |
| * 0201113 | 5914 | 579 | 6F | 3B | 9207 |
| * 0201113 | 6057 | 143 | 1Z | 6F | 9301 |
| *** 0201113** | **6780** | **723** | **7C** | **3B** | **9404** |
| * 0201114 | 4807 | 1100 | 3M | 5C | 9111 |
| *** 0201114** | **5159** | **352** | **3W** | **3A** | **9409** |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0201117 | 6415 | 15 | 3T | 7C | 9302 |
| *** 0201117** | **6521** | **106** | **4B** | **3B** | **9306** |
| * 0201118 | 5056 | 67 | 6F | 7D | 9001 |
| * 0201118 | 5094 | 0 | 4A | 6F | 9008 |
| *** 0201118** | **5480** | **386** | **3W** | **3W** | **9109** |
| * 0201119 | 5247 | 0 | 1G | 7C | 9107 |
| * 0201119 | 5569 | 322 | 6Q | 7C | 9203 |
| *** 0201119** | **5600** | **31** | **6F** | **4P** | **9304** |
| * 0201120 | 5041 | 15 | 6N | 7D | 9005 |
| * 0201120 | 5041 | 0 | 6Q | 4A | 9101 |
| * 0201120 | 5464 | 423 | 3R | 6Q | 9305 |
| *** 0201120** | **5494** | **30** | **3W** | **1Z** | **9402** |
| * 0201121 | 2913 | 1423 | 5Q | 4M | 9108 |
| * 0201124 | 2360 | 959 | 1G | 3Q | 9106 |
| * 0201124 | 2530 | 170 | 1Z | 1R | 9203 |
| * 0201124 | 2920 | 390 | 3R | 5G | 9403 |
| * 0201127 | 4525 | 294 | 4M | 7C | 9003 |
| * 0201127 | 4600 | 75 | 6F | 4M | 9202 |
| * 0201127 | 4825 | 225 | 4R | 6F | 9209 |
| * 0201127 | 4828 | 3 | 3D | 4R | 9302 |
| * 0202001 | 5199 | 1470 | 3T | 6F | 9208 |
| * 0202003 | 4538 | 822 | 1G | 5C | 9011 |
| * 0202003 | 5276 | 738 | 3R | 1G | 9302 |
| * 0202003 | 6265 | 989 | 5Q | 3R | 9501 |
| * 0202004 | 5774 | 692 | 3R | 7C | 9201 |
| * 0202005 | 4762 | 615 | 1Z | 3Q | 8912 |
| * 0202005 | 5212 | 450 | 3Q | 1Z | 9108 |
| * 0202005 | 5317 | 105 | 1W | 3Q | 9201 |
| *** 0202005** | **5975** | **658** | **7C** | **3T** | **9402** |
| * 0202006 | 6106 | 668 | 6P | 7D | 9309 |
| * 0202007 | 2311 | 533 | 3T | 7C | 9206 |
| * 0202007 | 2562 | 251 | 1Z | 3W | 9309 |
| * 0202007 | 3053 | 491 | 6J | 1Z | 9410 |
| * 0202008 | 3505 | 51 | 3Q | 1Z | 9107 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| | Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|---|
| * | 0202009 | 5251 | 0 | 2N | 1G | 9108 |
| * | 0202009 | 5251 | 406 | 1G | 7C | 9108 |
| * | 0202009 | 5908 | 0 | 3B | 7C | 9212 |
| * | 0202009 | 5997 | 89 | 5Q | 3B | 9306 |
| * | 0202009 | 6390 | 393 | 6N | 3B | 9411 |
| * | 0202010 | 4107 | 415 | 1G | 5C | 9004 |
| * | 0202010 | 4406 | 299 | 3Q | 3Q | 9110 |
| * | 0202011 | 4048 | 358 | 3Q | 7C | 9201 |
| * | 0202011 | 4051 | 3 | 3R | 3T | 9306 |
| * | 0202012 | 4532 | 385 | 6E | 1Z | 9003 |
| * | 0202012 | 5812 | 427 | 6F | 7D | 9301 |
| * | 0202012 | 6559 | 747 | 6J | 6F | 9409 |
| * | 0202014 | 3663 | 1353 | 6N | 7E | 9212 |
| * | 0202015 | 4361 | 1327 | 3A | 5C | 9104 |
| * | **0202015** | **5191** | **830** | **4D** | **1Z** | **9403** |
| * | 0202016 | 5411 | 504 | 1Z | 3R | 9109 |
| * | 0202018 | 4135 | 229 | 1Z | 3R | 8912 |
| * | **0202018** | **4405** | **270** | **3W** | **1Z** | **9304** |
| * | 0202022 | 4387 | 40 | 3T | 7D | 9006 |
| * | 0202022 | 5880 | 640 | 5Q | 3B | 9501 |
| * | 0202023 | 4757 | 770 | 3P | 1Z | 9012 |
| * | 0202023 | 5504 | 747 | 5Q | 3P | 9204 |
| * | 0202024 | 3979 | 508 | 1W | 7C | 9002 |
| * | 0202024 | 4778 | 67 | 3D | 7D | 9105 |
| * | 0202024 | 4908 | 130 | 3P | 3D | 9202 |
| * | 0202025 | 5229 | 0 | 3R | 5D | 9102 |
| * | 0202025 | 5229 | 954 | 5C | 1Z | 9101 |
| * | 0202025 | 5380 | 151 | 1W | 3R | 9201 |
| * | 0202026 | 5538 | 516 | 1Z | 5C | 8912 |
| * | **0202026** | **6021** | **483** | **4D** | **6P** | **9207** |
| * | 0202027 | 4412 | 1441 | 3T | 7K | 9003 |
| * | **0202027** | **6795** | **2383** | **7C** | **7C** | **9501** |
| * | 0202028 | 4117 | 998 | 5Q | 3Q | 9112 |
| * | 0202028 | 4694 | 517 | 6Q | 3T | 9302 |
| * | 0202029 | 5509 | 975 | 2S | 7C | 9207 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202030 | 3567 | 688 | 1Z | 2N | 9005 |
| * 0202030 | 3846 | 279 | 1Z | 1Z | 9010 |
| * 0202030 | 4972 | 1126 | 5Q | 1Z | 9308 |
| * 0202031 | 5534 | 791 | 6F | 6Q | 9007 |
| * 0202031 | 5880 | 346 | 5Q | 6F | 9112 |
| *** 0202031** | **6464** | **584** | **7C** | **3T** | **9303** |
| * 0202033 | 4307 | 1183 | 3A | 8F | 9003 |
| * 0202033 | 4600 | 293 | 5C | 3U | 9301 |
| * 0202034 | 2929 | 155 | 5W | 7C | 8910 |
| * 0202034 | 4141 | 1212 | 3Q | 5C | 9204 |
| * 0202035 | 3213 | 595 | 3U | 7C | 9102 |
| * 0202035 | 3215 | 2 | 3A | 3U | 9110 |
| * 0202035 | 3297 | 82 | 1W | 3A | 9202 |
| * 0202036 | 6133 | 1066 | 3Q | 7C | 8910 |
| * 0202036 | 6666 | 1 | 5Q | 7D | 9107 |
| * 0202036 | 6786 | 120 | 2S | 5Q | 9112 |
| * 0202036 | 7037 | 251 | 3T | 2S | 9208 |
| * 0202037 | 4957 | 2 | 6F | 7K | 9002 |
| * 0202037 | 5283 | 326 | 5C | 3W | 9403 |
| * 0202038 | 3566 | 942 | 1Z | 7D | 9010 |
| *** 0202038** | **4184** | **618** | **3W** | **1Z** | **9112** |
| * 0202042 | 5606 | 596 | 3R | 7C | 9207 |
| * 0202042 | 5606 | 596 | 7K | 7C | 9212 |
| * 0202042 | 5784 | 178 | 1T | 7K | 9305 |
| * 0202045 | 2885 | 485 | 6J | 1Z | 8910 |
| * 0202045 | 2929 | 44 | 3R | 5C | 9003 |
| * 0202045 | 3008 | 79 | 5Q | 3U | 9109 |
| * 0202045 | 3310 | 302 | 3R | 7D | 9208 |
| * 0202047 | 3512 | 210 | 1W | 1A | 9302 |
| * 0202047 | 3652 | 140 | 5Q | 1W | 9305 |
| * 0202048 | 5037 | 424 | 1W | 1Z | 9203 |
| * 0202048 | 5976 | 939 | 1Z | 3T | 9412 |
| * 0202049 | 5186 | 1320 | 5Q | 1Z | 9002 |
| * 0202049 | 5196 | 10 | 8P | 5Q | 9008 |
| * 0202049 | 5468 | 272 | 5Q | 6A | 9108 |
| * 0202049 | 6041 | 573 | 3R | 5Q | 9303 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| | Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|---|
| * | 0202051 | 3605 | 480 | 3A | 2N | 9101 |
| * | 0202051 | 3989 | 384 | 6N | 3R | 9205 |
| * | 0202051 | 4118 | 129 | 5Q | 6N | 9210 |
| * | **0202051** | **4688** | **570** | **4D** | **3B** | **9411** |
| * | 0202052 | 4466 | 555 | 3A | 7C | 9206 |
| * | 0202053 | 5762 | 761 | 3Q | 7C | 9105 |
| * | 0202053 | 6011 | 249 | 3R | 3Q | 9302 |
| * | 0202053 | 6243 | 232 | 8F | 3R | 9307 |
| * | 0202054 | 3314 | 656 | 5C | 5B | 9001 |
| * | 0202054 | 3349 | 35 | 6F | 5C | 9006 |
| * | 0202054 | 3814 | 465 | 3M | 6F | 9204 |
| * | 0202055 | 5376 | 592 | 7L | 6F | 9007 |
| * | 0202055 | 5387 | 11 | 1W | 7L | 9009 |
| * | **0202055** | **6372** | **985** | **7C** | **3T** | **9404** |
| * | 0202056 | 3600 | 1103 | 3R | 7C | 9203 |
| * | **0202056** | **4292** | **692** | **7C** | **3R** | **9301** |
| * | 0202058 | 5065 | 320 | 4R | 7D | 9002 |
| * | **0202058** | **5164** | **99** | **3W** | **4R** | **9405** |
| * | 0202060 | 4917 | 460 | 6M | 5D | 8910 |
| * | 0202060 | 5339 | 422 | 3R | 6A | 9103 |
| * | 0202062 | 4464 | 40 | 1W | 7C | 9002 |
| * | 0202062 | 5027 | 563 | 3A | 2N | 9106 |
| * | **0202062** | **6561** | **1534** | **7C** | **7D** | **9406** |
| * | 0202063 | 3016 | 722 | 5D | 8F | 8911 |
| * | 0202063 | 3131 | 115 | 7K | 3B | 9008 |
| * | 0202063 | 3136 | 5 | 8C | 7K | 9103 |
| * | 0202063 | 3716 | 0 | 3B | 7C | 9401 |
| * | 0202063 | 3751 | 35 | 7K | 3B | 9403 |
| * | 0202064 | 5122 | 0 | 7A | 7A | 9001 |
| * | 0202064 | 5122 | 809 | 7A | 5C | 8912 |
| * | 0202064 | 5834 | 5 | 2S | 7C | 9401 |
| * | 0202065 | 3090 | 436 | 8F | 7C | 9203 |
| * | 0202065 | 3212 | 122 | 3Q | 3T | 9304 |
| * | 0202067 | 2761 | 1096 | 3P | 5C | 9203 |
| * | **0202067** | **3152** | **391** | **7C** | **3P** | **9405** |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202068 | 4683 | 236 | 5Q | 7C | 9302 |
| * 0202068 | 5022 | 338 | 1W | 5Q | 9402 |
| * 0202069 | 5422 | 0 | 2Q | 7K | 9312 |
| * 0202069 | 5422 | 138 | 7K | 7D | 9205 |
| * 0202070 | 4390 | 3 | 5Q | 7C | 9201 |
| * 0202070 | 5625 | 1235 | 7T | 5Q | 9406 |
| * 0202071 | 3943 | 178 | 1W | 7C | 9201 |
| * 0202072 | 3636 | 1638 | 5Q | 1Z | 8910 |
| *** 0202072** | **4386** | **750** | **4D** | **5Q** | **9110** |
| * 0202074 | 3558 | 199 | 2N | 3W | 9005 |
| * 0202074 | 4217 | 659 | 6Q | 2N | 9204 |
| *** 0202074** | **4867** | **650** | **7C** | **3R** | **9402** |
| * 0202075 | 2865 | 1006 | 5C | 3T | 9010 |
| * 0202075 | 4219 | 1354 | 6N | 5C | 9312 |
| * 0202075 | 4225 | 0 | 3R | 8F | 9406 |
| * 0202075 | 4225 | 6 | 2N | 7C | 9405 |
| * 0202075 | 4239 | 14 | 8C | 3B | 9408 |
| * 0202076 | 3715 | 83 | 2N | 7C | 9002 |
| * 0202076 | 4161 | 327 | 5Q | 7C | 9111 |
| * 0202078 | 2976 | 99 | 1Z | 4D | 9207 |
| * 0202078 | 3057 | 81 | 3R | 1Z | 9307 |
| *** 0202078** | **3439** | **382** | **7C** | **3R** | **9501** |
| * 0202080 | 5481 | 3 | 3P | 7C | 8911 |
| * 0202080 | 5483 | 2 | 3P | 3M | 8912 |
| *** 0202080** | **7223** | **1740** | **7C** | **7C** | **9407** |
| * 0202081 | 5641 | 1283 | 3R | 4P | 9301 |
| * 0202083 | 3548 | 405 | 2C | 7J | 9006 |
| * 0202083 | 4683 | 1135 | 1G | 2C | 9309 |
| * 0202084 | 6540 | 70 | 1B | 7D | 9206 |
| * 0202085 | 4858 | 82 | 1W | 7D | 9005 |
| *** 0202085** | **5412** | **554** | **4D** | **3T** | **9301** |
| * 0202086 | 2080 | 116 | 3Q | 3R | 9003 |
| * 0202086 | 2147 | 67 | 3T | 2S | 9009 |
| * 0202086 | 2355 | 11 | 2S | 5W | 9302 |
| * 0202086 | 2572 | 217 | 6Q | 2S | 9409 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| | Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|---|
| * | 0202087 | 4339 | 1285 | 5Q | 7K | 9103 |
| * | 0202087 | 4406 | 67 | 5Q | 5Q | 9109 |
| * | 0202088 | 4828 | 912 | 3R | 1G | 9207 |
| * | 0202088 | 6054 | 362 | 6F | 7C | 9502 |
| * | 0202089 | 4435 | 226 | 7A | 5C | 9007 |
| * | 0202089 | 4442 | 7 | 7J | 7J | 9008 |
| * | 0202089 | 4971 | 529 | 3Q | 7J | 9202 |
| * | 0202089 | 4987 | 16 | 5D | 6Q | 9404 |
| * | 0202090 | 3437 | 0 | 2C | 2A | 9110 |
| * | 0202090 | 3437 | 376 | 1Z | 7C | 9101 |
| * | **0202090** | **4509** | **1072** | **4B** | **2C** | **9308** |
| * | 0202091 | 4062 | 168 | 1Z | 7D | 9012 |
| * | 0202091 | 4062 | 168 | 5C | 7D | 9103 |
| * | 0202091 | 4676 | 614 | 2C | 6Q | 9302 |
| * | 0202092 | 3475 | 228 | 1G | 5C | 9106 |
| * | 0202093 | 4613 | 703 | 3R | 7C | 9312 |
| * | 0202095 | 5694 | 89 | 1Z | 7C | 9101 |
| * | 0202096 | 2036 | 0 | 3B | 7C | 9104 |
| * | 0202096 | 3318 | 1282 | 6R | 3B | 9502 |
| * | 0202097 | 4905 | 864 | 3R | 7C | 9411 |
| * | 0202098 | 4246 | 333 | 7K | 5Q | 9008 |
| * | 0202098 | 4847 | 601 | 8B | 7K | 9110 |
| * | 0202101 | 4326 | 852 | 3A | 3Q | 9002 |
| * | 0202101 | 5186 | 860 | 1Z | 3A | 9303 |
| * | 0202101 | 5229 | 43 | 3R | 3B | 9305 |
| * | 0202101 | 5477 | 248 | 6F | 3R | 9403 |
| * | 0202102 | 4727 | 921 | 3A | 5C | 9003 |
| * | 0202102 | 5527 | 800 | 8C | 3A | 9311 |
| * | 0202103 | 2550 | 0 | 8B | 7A | 9409 |
| * | 0202106 | 2374 | 0 | 7J | 7C | 9010 |
| * | 0202106 | 2867 | 493 | 5Q | 3B | 9107 |
| * | 0202106 | 3395 | 528 | 4D | 5Q | 9406 |
| * | 0202107 | 1273 | 74 | 3R | | 9003 |
| * | 0202107 | 1305 | 32 | 6K | 3R | 9107 |
| * | **0202107** | **2327** | **1022** | **7D** | **6K** | **9403** |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202108 | 5255 | 340 | 1W | 3R | 9406 |
| *** 0202108** | **5637** | **382** | **7C** | **3B** | **9501** |
| * 0202109 | 5232 | 1443 | 6N | 2N | 9501 |
| * 0202111 | 5749 | 995 | 5C | 7C | 9309 |
| * 0202113 | 4165 | 382 | 1Z | 5Q | 9008 |
| * 0202113 | 5051 | 886 | 7K | 1Z | 9206 |
| * 0202116 | 5367 | 337 | 7K | 7D | 9306 |
| * 0202117 | 3939 | 1042 | 5Q | 1W | 9105 |
| * 0202117 | 4513 | 25 | 3R | 7C | 9501 |
| * 0202119 | 4607 | 1497 | 3P | 7K | 9401 |
| * 0202119 | 4681 | 74 | 3D | 3P | 9406 |
| * 0202120 | 2920 | 660 | 5C | 7C | 8912 |
| * 0202120 | 2994 | 74 | 8P | 5C | 9008 |
| * 0202120 | 3405 | 411 | 3T | 3B | 9203 |
| *** 0202120** | **4254** | **849** | **7D** | **3T** | **9402** |
| * 0202121 | 5854 | 338 | 3A | 7C | 9111 |
| * 0202122 | 4950 | 814 | 5Q | 2N | 9010 |
| * 0202122 | 5234 | 284 | 8F | 5Q | 9212 |
| * 0202123 | 6375 | 266 | 3T | 7D | 9502 |
| * 0202125 | 5802 | 704 | 7L | 1Z | 8912 |
| * 0202125 | 6418 | 616 | 1Z | 7L | 9110 |
| * 0202126 | 6789 | 1152 | 3T | 5Q | 9307 |
| * 0202127 | 5584 | 291 | 1Z | 5G | 8911 |
| * 0202127 | 5830 | 246 | 1Z | 1Z | 9008 |
| * 0202127 | 5990 | 160 | 3Q | 1Z | 9102 |
| * 0202127 | 6790 | 960 | 7K | 1Z | 9209 |
| * 0202128 | 4375 | 557 | 1Z | 5C | 9103 |
| * 0202128 | 4955 | 580 | 6N | 7C | 9311 |
| * 0202130 | 5239 | 681 | 1Z | 3T | 9102 |
| * 0202130 | 7004 | 84 | 3T | 7C | 9404 |
| * 0202131 | 4540 | 404 | 3Q | 7C | 9003 |
| * 0202131 | 6129 | 998 | 2N | 7D | 9304 |
| * 0202132 | 5510 | 1490 | 3R | 2N | 9303 |
| * 0202133 | 3777 | 560 | 1Z | 3R | 9102 |
| *** 0202133** | **4369** | **592** | **7C** | **1Z** | **9406** |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202134 | 5203 | 1115 | 3Q | 7K | 9101 |
| *** 0202134** | **5887** | **684** | **7C** | **7C** | **9409** |
| * 0202137 | 4753 | 916 | 1Z | 4D | 9003 |
| * 0202137 | 4848 | 115 | 5W | 1Z | 9105 |
| * 0202137 | 5359 | 3 | 3P | 3B | 9212 |
| * 0202137 | 5361 | 0 | 3P | 3B | 9303 |
| * 0202137 | 5361 | 0 | 3P | 3P | 9307 |
| * 0202137 | 5361 | 0 | 3P | 3B | 9311 |
| * 0202137 | 5361 | 2 | 3P | 3P | 9302 |
| * 0202138 | 4726 | 1389 | 5Q | 7C | 9206 |
| * 0202138 | 4766 | 40 | 5Q | 3B | 9401 |
| * 0202138 | 5168 | 402 | 6B | 5Q | 9410 |
| * 0202139 | 4658 | 404 | 5Q | 3Q | 9007 |
| *** 0202139** | **4938** | **280** | **3W** | **7C** | **9501** |
| * 0202140 | 2564 | 393 | 3A | 7C | 9011 |
| * 0202141 | 4557 | 242 | 6F | 7C | 9105 |
| * 0202141 | 4946 | 389 | 3A | 6F | 9207 |
| * 0202142 | 5726 | 850 | 2N | 8F | 9102 |
| * 0202142 | 6080 | 354 | 2A | 2N | 9210 |
| *** 0202142** | **6285** | **205** | **3W** | **5C** | **9406** |
| * 0202143 | 5175 | 1026 | 3P | 7C | 9202 |
| *** 0202143** | **6424** | **1249** | **7C** | **3B** | **9501** |
| * 0202146 | 3518 | 892 | 5Q | 2N | 9010 |
| * 0202146 | 3573 | 55 | 1W | 3Q | 9404 |
| * 0202146 | 3575 | 2 | 7K | 3B | 9302 |
| * 0202147 | 5165 | 761 | 2F | 5C | 9110 |
| * 0202147 | 5555 | 390 | 2F | 6F | 9303 |
| * 0202149 | 4595 | 485 | 3A | 7C | 9003 |
| * 0202149 | 5745 | 1150 | 3R | 3W | 9312 |
| * 0202150 | 6417 | 0 | 1W | 7C | 9201 |
| *** 0202150** | **7042** | **625** | **3W** | **6N** | **9410** |
| * 0202151 | 4353 | 467 | 5D | 3P | 9003 |
| * 0202151 | 4906 | 553 | 7A | 5D | 9110 |
| *** 0202151** | **5302** | **396** | **3W** | **4M** | **9410** |
| * 0202154 | 5606 | 859 | 5C | 7C | 9210 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| | Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|---|
| * | 0202155 | 4072 | 143 | 1Z | 7C | 9008 |
| * | 0202155 | 4836 | 59 | 3B | 3W | 9407 |
| * | 0202156 | 6631 | 0 | 6A | 5W | 9309 |
| * | 0202156 | 6631 | 90 | 5W | 3B | 9207 |
| * | 0202156 | 6739 | 108 | 5W | 5W | 9412 |
| * | 0202157 | 3418 | 212 | 8B | 7G | 9111 |
| * | 0202157 | 4566 | 1148 | 5Q | 8B | 9411 |
| * | 0202158 | 5234 | 202 | 3Q | 5C | 8912 |
| * | 0202158 | 5522 | 288 | 2N | 3B | 9303 |
| * | 0202160 | 4784 | 567 | 8P | 7C | 9106 |
| * | 0202160 | 4818 | 34 | 3T | 5W | 9108 |
| * | 0202160 | 4880 | 62 | 5Q | 3T | 9110 |
| * | **0202160** | **5754** | **874** | **7C** | **5Q** | **9410** |
| * | 0202161 | 4515 | 653 | 1Z | 3W | 9005 |
| * | 0202161 | 5472 | 957 | 3Q | 1Z | 9302 |
| * | 0202163 | 3395 | 380 | 3R | 7C | 9306 |
| * | 0202164 | 5017 | 337 | 3A | 7C | 9004 |
| * | 0202164 | 6124 | 1107 | 1Z | 3A | 9210 |
| * | 0202164 | 6622 | 498 | 4R | 3B | 9401 |
| * | **0202164** | **6852** | **230** | **3W** | **4R** | **9408** |
| * | 0202166 | 4009 | 250 | 3Q | 7C | 9106 |
| * | 0202166 | 5124 | 1115 | 3B | 3Q | 9311 |
| * | 0202167 | 4022 | 937 | 1W | 5Q | 9201 |
| * | 0202167 | 4492 | 470 | 5Q | 3T | 9304 |
| * | 0202167 | 4898 | 406 | 1T | 5Q | 9401 |
| * | **0202167** | **4923** | **25** | **4D** | **1T** | **9407** |
| * | 0202168 | 608 | 0 | 3R | 4D | 9401 |
| * | 0202169 | 4511 | 0 | 5Q | 5Q | 8911 |
| * | 0202169 | 4625 | 114 | 1Z | 5Q | 9012 |
| * | 0202169 | 6178 | 1011 | 6N | 6A | 9311 |
| * | 0202171 | 4182 | 362 | 3A | 7K | 9002 |
| * | 0202171 | 4660 | 478 | 7K | 3A | 9107 |
| * | 0202171 | 4974 | 314 | 1Z | 7K | 9209 |
| * | 0202171 | 4994 | 20 | 8F | 1Z | 9210 |
| * | 0202171 | 5063 | 69 | 2N | 8F | 9306 |
| * | 0202172 | 5743 | 355 | 3R | 7D | 9404 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202173 | 3010 | 1030 | 5Q | 2C | 9012 |
| * 0202173 | 3300 | 290 | 5Q | 5Q | 9110 |
| * 0202173 | 3365 | 65 | 3T | 5Q | 9203 |
| * 0202173 | 4089 | 724 | 3R | 3T | 9405 |
| * 0202174 | 5997 | 1360 | 5C | 7C | 9104 |
| *** 0202174** | **7244** | **1247** | **7C** | **3T** | **9412** |
| * 0202176 | 4008 | 11 | 2N | 1Z | 8912 |
| *** 0202176** | **4607** | **599** | **3W** | **2N** | **9109** |
| * 0202178 | 5254 | 1062 | 5C | 4D | 9106 |
| *** 0202178** | **5853** | **599** | **3W** | **5C** | **9311** |
| * 0202179 | 4201 | 101 | 3M | 3W | 9302 |
| * 0202181 | 5997 | 1513 | 5Q | 7C | 9102 |
| * 0202181 | 6927 | 930 | 8B | 5Q | 9205 |
| *** 0202181** | **7630** | **703** | **7C** | **6F** | **9403** |
| * 0202182 | 6570 | 1336 | 3M | 7C | 9205 |
| * 0202182 | 6822 | 252 | 1Z | 7C | 9405 |
| * 0202183 | 5624 | 1430 | 1Z | 5C | 9109 |
| *** 0202183** | **7209** | **1585** | **4D** | **1Z** | **9409** |
| * 0202185 | 3979 | 0 | 2A | 3Q | 9001 |
| * 0202185 | 5221 | 0 | 8B | 3R | 9412 |
| * 0202185 | 5221 | 1242 | 3R | 5D | 9303 |
| * 0202186 | 4357 | 381 | 2N | 1Z | 9005 |
| * 0202186 | 4361 | 4 | 5Q | 7C | 9107 |
| * 0202186 | 4459 | 98 | 3A | 5Q | 9112 |
| * 0202186 | 5228 | 157 | 3T | 7C | 9412 |
| * 0202188 | 5474 | 1373 | 2N | 5C | 9009 |
| * 0202188 | 6122 | 648 | 1Z | 2N | 9108 |
| * 0202189 | 5280 | 652 | 5Q | 7C | 9304 |
| *** 0202189** | **5436** | **156** | **3W** | **5Q** | **9405** |
| * 0202192 | 5169 | 1932 | 2N | 5C | 9202 |
| * 0202192 | 5867 | 698 | 1Z | 1W | 9305 |
| *** 0202192** | **6033** | **166** | **7C** | **1Z** | **9411** |
| * 0202195 | 4615 | 727 | 7K | 7C | 9207 |
| * 0202196 | 4275 | 1105 | 5W | 3D | 9204 |
| *** 0202196** | **4778** | **503** | **3W** | **3T** | **9405** |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202197 | 5577 | 1116 | 3Q | 7K | 9201 |
| * 0202197 | 5766 | 189 | 3R | 7D | 9208 |
| * 0202201 | 4643 | 1482 | 5Q | 6A | 9005 |
| * 0202201 | 5568 | 925 | 5Q | 5Q | 9211 |
| * 0202203 | 3448 | 679 | 1Z | 3Q | 9007 |
| * 0202203 | 3495 | 47 | 5W | 1Z | 9101 |
| * 0202203 | 4823 | 496 | 3T | 7C | 9312 |
| * 0202204 | 5260 | 804 | 5B | 2S | 9012 |
| * 0202204 | 6388 | 1128 | 2Q | 5B | 9409 |
| * 0202205 | 4933 | 914 | 1Z | 5G | 9101 |
| * 0202205 | 5163 | 230 | 8F | 1Z | 9206 |
| * 0202206 | 3892 | 57 | 3P | 3P | 9001 |
| * 0202206 | 5359 | 30 | 3T | 6A | 9412 |
| * 0202207 | 5319 | 434 | 1Z | 5Q | 9006 |
| *** 0202207** | **6793** | **1474** | **7C** | **1Z** | **9311** |
| * 0202208 | 4624 | 688 | 6Q | 5B | 9003 |
| * 0202208 | 4649 | 25 | 3R | 6Q | 9009 |
| * 0202208 | 5348 | 699 | 8B | 3Q | 9308 |
| * 0202209 | 4521 | 0 | 3R | 6P | 9104 |
| * 0202209 | 4521 | 401 | 6P | 7C | 9005 |
| *** 0202209** | **5335** | **814** | **5G** | **3R** | **9302** |
| * 0202210 | 4294 | 1170 | 1A | 5G | 9311 |
| * 0202210 | 4489 | 195 | 5C | 1A | 9406 |
| * 0202211 | 3413 | 62 | 3U | 8F | 9001 |
| * 0202211 | 4099 | 218 | 1Z | 7D | 9205 |
| * 0202211 | 4489 | 390 | 7A | 1Z | 9302 |
| * 0202212 | 5383 | 320 | 2N | 7C | 9201 |
| * 0202212 | 5881 | 498 | 3R | 2N | 9411 |
| * 0202213 | 5521 | 1316 | 6F | 1Z | 9008 |
| * 0202213 | 5868 | 347 | 1A | 3B | 9301 |
| * 0202214 | 5431 | 459 | 3T | 7D | 9201 |
| * 0202217 | 5282 | 323 | 6J | 7C | 9104 |
| * 0202217 | 5476 | 194 | 3B | 6K | 9111 |
| *** 0202217** | **6422** | **946** | **7C** | **3P** | **9305** |
| * 0202219 | 4854 | 785 | 3R | 5G | 9109 |
| *** 0202219** | 5426 | 572 | 7C | 3R | 9311 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202220 | 2913 | 315 | 1Z | 1Z | 9001 |
| * 0202220 | 3029 | 116 | 3M | 1Z | 9012 |
| * 0202220 | 3760 | 731 | 8F | 7C | 9306 |
| * **0202220** | **3774** | **14** | **4D** | **8F** | **9407** |
| * 0202223 | 6509 | 0 | 6J | 3T | 9001 |
| * 0202223 | 6626 | 117 | 3R | 6Y | 9005 |
| * 0202223 | 7040 | 414 | 3A | 3R | 9210 |
| * 0202223 | 7140 | 100 | 3T | 3R | 9407 |
| * 0202224 | 5164 | 902 | 1Z | 3Q | 9101 |
| * 0202224 | 5764 | 600 | 3R | 1Z | 9307 |
| * 0202225 | 7240 | 1092 | 7A | 7D | 9305 |
| * 0202226 | 3405 | 361 | 3A | 3W | 9005 |
| * 0202226 | 4554 | 1149 | 3T | 3A | 9306 |
| * 0202227 | 5467 | 958 | 1Z | 7H | 9103 |
| * 0202227 | 5667 | 200 | 6N | 3Q | 9306 |
| * 0202227 | 5927 | 460 | 3R | 3Q | 9406 |
| * 0202228 | 5768 | 817 | 6F | 3W | 9203 |
| * 0202228 | 5868 | 100 | 7A | 6F | 9209 |
| * 0202229 | 3871 | 399 | 5Q | 3Q | 8910 |
| * 0202229 | 4097 | 226 | 1W | 5Q | 9203 |
| * 0202231 | 4851 | 1179 | 3A | 7K | 9105 |
| * 0202231 | 5378 | 527 | 3R | 3R | 9304 |
| * 0202232 | 5412 | 1514 | 3A | 1Z | 9101 |
| * 0202232 | 6418 | 1007 | 5Q | 3R | 9212 |
| * 0202233 | 5394 | 1370 | 1W | 3Q | 9003 |
| * 0202233 | 5439 | 45 | 5D | 3T | 9008 |
| * 0202233 | 5634 | 195 | 8C | 3Q | 9105 |
| * 0202234 | 3815 | 190 | 1Z | 1Z | 9012 |
| * 0202234 | 4121 | 306 | 1W | 3W | 9110 |
| * 0202234 | 4206 | 85 | 5Q | 3T | 9205 |
| * 0202235 | 5045 | 832 | 2S | 3R | 9101 |
| * 0202235 | 5050 | 1 | 5Q | 3D | 9205 |
| * **0202235** | **5780** | **730** | **3W** | **5Q** | **9410** |
| * 0202236 | 5812 | 1350 | 7J | 7D | 9008 |
| * 0202236 | 7010 | 1198 | 3T | 1B | 9405 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202237 | 4470 | 66 | 2S | 7C | 8912 |
| *** 0202237** | **5241** | **771** | **7C** | **2S** | **9106** |
| * 0202239 | 4367 | 896 | 5W | 5C | 9012 |
| * 0202239 | 4595 | 228 | 9J | 5W | 9207 |
| * 0202239 | 5286 | 691 | 6F | 9J | 9310 |
| * 0202241 | 4777 | 510 | 3A | 7C | 9201 |
| * 0202241 | 4981 | 204 | 5Q | 8B | 9309 |
| * 0202241 | 5365 | 384 | 3T | 6A | 9411 |
| * 0202242 | 6240 | 1456 | 1Z | 7C | 9310 |
| * 0202244 | 4892 | 401 | 4P | 3D | 9301 |
| * 0202245 | 4226 | 0 | 2S | 7C | 8912 |
| *** 0202245** | **4275** | **49** | **3W** | **2S** | **9106** |
| * 0202247 | 3621 | 879 | 3Q | 7C | 9005 |
| *** 0202247** | **5124** | **1503** | **7C** | **6P** | **9405** |
| * 0202248 | 4340 | 865 | 1Z | 7K | 9205 |
| * 0202248 | 5183 | 843 | 7K | 1Z | 9410 |
| * 0202250 | 4946 | 733 | 5Q | 7C | 9012 |
| * 0202250 | 5015 | 69 | 5Q | 5Q | 9103 |
| * 0202251 | 2661 | 169 | 4P | 4B | 9312 |
| * 0202252 | 4334 | 1447 | 3R | 7K | 9304 |
| *** 0202252** | **4337** | **3** | **3W** | **3R** | **9412** |
| * 0202254 | 5922 | 149 | 5Q | 7C | 9202 |
| *** 0202254** | **6670** | **748** | **3W** | **5Q** | **9408** |
| * 0202256 | 5258 | 216 | 6J | 7D | 9208 |
| * 0202257 | 6791 | 790 | 3T | 7C | 9304 |
| *** 0202257** | **6796** | **5** | **3W** | **3T** | **9312** |
| * 0202259 | 3098 | 304 | 1Z | 1Z | 8911 |
| * 0202259 | 3994 | 896 | 3Q | 1Z | 9201 |
| *** 0202259** | **4452** | **458** | **4D** | **1T** | **9312** |
| * 0202260 | 5618 | 1175 | 8C | 7C | 9010 |
| * 0202260 | 6536 | 918 | 1Z | 7C | 9302 |
| * 0202260 | 6901 | 0 | 7K | 3T | 9403 |
| * 0202260 | 6901 | 0 | 6R | 7K | 9502 |
| * 0202260 | 6901 | 365 | 3T | 1Z | 9401 |
| * 0202261 | 5025 | 436 | 2S | 3Q | 9007 |
| * 0202261 | 6696 | 1212 | 1W | 7D | 9402 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| | Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|---|
| * | 0202262 | 5036 | 0 | 3W | 6F | 9201 |
| * | 0202262 | 5036 | 696 | 3Q | 3P | 8911 |
| * | 0202262 | 5445 | 409 | 3M | 3P | 9302 |
| * | 0202262 | 5446 | 1 | 3P | 3B | 9303 |
| * | 0202263 | 5772 | 530 | 1Z | 7C | 9109 |
| * | **0202263** | **6402** | **630** | **7C** | **1Z** | **9312** |
| * | 0202264 | 4124 | 78 | 3Q | 3B | 9104 |
| * | 0202264 | 5453 | 227 | 3R | 7C | 9409 |
| * | 0202265 | 4522 | 667 | 5Q | 7K | 9210 |
| * | 0202265 | 4890 | 368 | 5Q | 3B | 9310 |
| * | 0202265 | 5161 | 271 | 5Q | 7K | 9407 |
| * | 0202266 | 3218 | 882 | 3P | 4J | 9006 |
| * | 0202266 | 3557 | 339 | 1G | 3B | 9104 |
| * | **0202266** | **3731** | **174** | **4D** | **4P** | **9305** |
| * | 0202267 | 5742 | 385 | 3Q | 4M | 9001 |
| * | 0202267 | 5753 | 11 | 7K | 6P | 9108 |
| * | 0202267 | 6593 | 840 | 3R | 3T | 9406 |
| * | 0202268 | 5627 | 1199 | 1Z | 3R | 9204 |
| * | 0202269 | 3912 | 332 | 5Q | 7C | 9102 |
| * | 0202269 | 4479 | 567 | 6Q | 5Q | 9303 |
| * | 0202271 | 5791 | 20 | 5C | 3W | 9004 |
| * | 0202271 | 5990 | 199 | 5Q | 5C | 9108 |
| * | **0202271** | **7211** | **1221** | **7C** | **5Q** | **9402** |
| * | 0202272 | 3895 | 0 | 3Q | 7C | 9001 |
| * | 0202272 | 5712 | 883 | 3R | 7D | 9405 |
| * | 0202272 | 5904 | 192 | 1Z | 3R | 9409 |
| * | 0202273 | 5078 | 1291 | 3A | 3W | 9201 |
| * | 0202274 | 3766 | 246 | 1G | 7C | 9402 |
| * | 0202276 | 6324 | 439 | 3R | 7C | 9406 |
| * | 0202278 | 5425 | 946 | 2N | 7C | 9002 |
| * | 0202278 | 5470 | 45 | 3Q | 2N | 9005 |
| * | 0202278 | 5485 | 15 | 8F | 3Q | 9104 |
| * | **0202278** | **6554** | **1069** | **4D** | **7C** | **9410** |
| * | 0202280 | 3762 | 355 | 3A | 7C | 9110 |
| * | 0202280 | 3968 | 206 | 6F | 3A | 9210 |
| * | 0202280 | 4499 | 0 | 2F | 6A | 9411 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202281 | 4928 | 1555 | 3A | 5Q | 9002 |
| * 0202281 | 4939 | 11 | 8P | 3A | 9008 |
| * 0202281 | 5954 | 1015 | 1Z | 6A | 9204 |
| *** 0202281** | **6295** | **341** | **7C** | **3B** | **9407** |
| * 0202282 | 5246 | 2 | 4P | 3R | 8912 |
| * 0202282 | 6497 | 0 | 3R | 7C | 9406 |
| *** 0202282** | **6497** | **1251** | **7C** | **4P** | **9405** |
| * 0202283 | 3718 | 570 | 2S | 7C | 9102 |
| * 0202283 | 3725 | 7 | 5W | 3B | 9109 |
| * 0202283 | 4243 | 518 | 3A | 5W | 9302 |
| * 0202284 | 4160 | 399 | 2N | 5C | 9109 |
| *** 0202284** | **4901** | **741** | **3W** | **7D** | **9407** |
| * 0202285 | 5401 | 1249 | 3D | 1Z | 9208 |
| * 0202285 | 6771 | 1370 | 5C | 3D | 9410 |
| * 0202286 | 1868 | 0 | 7K | 1Z | 8911 |
| *** 0202286** | **2647** | **779** | **7C** | **3D** | **9402** |
| * 0202288 | 4211 | 934 | 3T | 5G | 9305 |
| * 0202288 | 4696 | 485 | 1W | 5Q | 9404 |
| * 0202289 | 5497 | 661 | 8F | 4B | 9403 |
| * 0202290 | 4214 | 422 | 3R | 7D | 9102 |
| * 0202290 | 4585 | 371 | 3Q | 3R | 9201 |
| * 0202290 | 4812 | 227 | 5Q | 3Q | 9301 |
| * 0202290 | 5430 | 618 | 5Q | 5Q | 9412 |
| * 0202291 | 4146 | 816 | 3R | 7C | 9005 |
| * 0202291 | 5302 | 1153 | 1W | 5C | 9406 |
| * 0202292 | 6532 | 802 | 5W | 7D | 9309 |
| * 0202293 | 4634 | 438 | 1Z | 8F | 9006 |
| * 0202293 | 4788 | 154 | 1Z | 1Z | 9012 |
| * 0202293 | 5399 | 611 | 5Q | 1Z | 9405 |
| * 0202294 | 3863 | 988 | 5Q | 7C | 8910 |
| * 0202294 | 4063 | 200 | 5Q | 5Q | 9201 |
| * 0202294 | 4750 | 887 | 6N | 5Q | 9303 |
| * 0202296 | 5268 | 778 | 5B | 4P | 9103 |
| * 0202296 | 5765 | 1275 | 8F | 4P | 9205 |
| *** 0202296** | **5788** | **23** | **3W** | **2N** | **9403** |
| * 0202297 | 5190 | 492 | 1W | 7C | 9201 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202298 | 4227 | 521 | 3M | 2N | 9206 |
| * 0202298 | 4295 | 68 | 3A | 7D | 9301 |
| * 0202299 | 5315 | 483 | 6F | 5G | 9002 |
| * 0202299 | 5795 | 480 | 7K | 6F | 9110 |
| *** 0202299** | **6862** | **1067** | **7C** | **1T** | **9408** |
| * 0202300 | 3956 | 862 | 1Z | 2S | 9101 |
| * 0202300 | 4363 | 407 | 3D | 1Z | 9110 |
| *** 0202300** | **5414** | **1051** | **7C** | **3D** | **9407** |
| * 0202301 | 3042 | 1007 | 7K | 7D | 9206 |
| * 0202301 | 3196 | 154 | 6N | 3B | 9307 |
| *** 0202301** | **3714** | **518** | **3W** | **6N** | **9407** |
| * 0202302 | 5082 | 211 | 1G | 5C | 9006 |
| * 0202304 | 3304 | 290 | 1Z | 7C | 9006 |
| * 0202304 | 4322 | 771 | 2N | 7D | 9311 |
| * 0202305 | 4349 | 391 | 3Q | 6F | 9010 |
| * 0202305 | 5087 | 738 | 5Q | 5C | 9209 |
| * 0202306 | 3383 | 113 | 1Z | 1Z | 9001 |
| * 0202306 | 3921 | 538 | 3D | 1Z | 9108 |
| * 0202306 | 4377 | 456 | 1Z | 7C | 9402 |
| * 0202307 | 5843 | 1157 | 3Q | 7C | 9208 |
| * 0202308 | 4269 | 0 | 2Q | 2C | 9107 |
| * 0202308 | 4541 | 272 | 1Z | 2Q | 9206 |
| * 0202308 | 4724 | 183 | 5W | 1Z | 9405 |
| * 0202311 | 3752 | 27 | 5C | 3R | 9004 |
| *** 0202311** | **4370** | **618** | **4D** | **5C** | **9404** |
| * 0202312 | 3465 | 216 | 6Q | 7C | 9103 |
| * 0202312 | 4022 | 557 | 2N | 3Q | 9304 |
| * 0202313 | 6150 | 391 | 7E | 7D | 9409 |
| * 0202315 | 4097 | 357 | 3T | 7C | 9011 |
| * 0202315 | 4492 | 241 | 6N | 3B | 9406 |
| * 0202317 | 4173 | 373 | 8B | 7C | 9110 |
| * 0202317 | 4238 | 65 | 1W | 3R | 9203 |
| * 0202317 | 4318 | 80 | 5C | 1W | 9208 |
| * 0202319 | 4970 | 268 | 1Z | 1Z | 9003 |
| * 0202319 | 5303 | 333 | 3B | 1Z | 9109 |
| * 0202319 | 5638 | 335 | 5Q | 5Q | 9210 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202321 | 4974 | 529 | 7K | 7C | 9205 |
| * 0202321 | 5074 | 99 | 1Z | 3T | 9209 |
| * 0202322 | 4100 | 189 | 5Q | 7C | 9009 |
| * 0202322 | 5098 | 998 | 1Z | 5Q | 9303 |
| * 0202322 | 5675 | 577 | 5W | 1Z | 9409 |
| * 0202323 | 4638 | 392 | 8P | 8C | 9009 |
| *** 0202323** | **5750** | **1112** | **7C** | **8P** | **9402** |
| * 0202324 | 3986 | 860 | 5C | 8F | 8911 |
| *** 0202324** | **4750** | **764** | **3W** | **3Q** | **9201** |
| * 0202325 | 5554 | 1056 | 8F | 7D | 9401 |
| * 0202326 | 4403 | 448 | 3A | 7K | 9002 |
| * 0202326 | 5083 | 3 | 3T | 7D | 9203 |
| *** 0202326** | **5406** | **323** | **4B** | **1W** | **9308** |
| * 0202327 | 6609 | 513 | 4R | 7D | 9209 |
| * 0202327 | 6781 | 172 | 7K | 4R | 9305 |
| * 0202328 | 2225 | 394 | 3R | 7C | 9001 |
| * 0202328 | 3381 | 635 | 5C | 7C | 9412 |
| * 0202330 | 5157 | 662 | 1Z | 7C | 9011 |
| * 0202331 | 3163 | 0 | 4A | 3A | 9008 |
| * 0202331 | 3163 | 421 | 3A | 5D | 9003 |
| * 0202331 | 4214 | 259 | 1Z | 7C | 9212 |
| * 0202333 | 4442 | 1121 | 5Q | 7C | 9201 |
| * 0202333 | 4966 | 524 | 8B | 5Q | 9304 |
| * 0202333 | 5292 | 326 | 3T | 7C | 9312 |
| * 0202334 | 5644 | 213 | 2N | 7D | 9303 |
| * 0202336 | 4776 | 179 | 8F | 5Q | 8910 |
| * 0202336 | 5155 | 15 | 3Q | 7C | 9104 |
| * 0202336 | 5380 | 225 | 3A | 3Q | 9208 |
| * 0202338 | 3678 | 0 | 7K | 7C | 9001 |
| * 0202338 | 3987 | 309 | 8C | 7K | 9010 |
| * 0202338 | 4494 | 507 | 2C | 2C | 9304 |
| * 0202339 | 6364 | 470 | 3P | 7D | 9410 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| | Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|---|
| * | 0202340 | 4595 | 227 | 5W | 5C | 9101 |
| * | 0202340 | 4615 | 20 | 2P | 5W | 9103 |
| * | 0202340 | 4619 | 4 | 1W | 4B | 9112 |
| * | 0202340 | 4860 | 221 | 3M | 3T | 9301 |
| * | **0202340** | **5413** | **553** | **7C** | **3P** | **9411** |
| * | 0202342 | 2825 | 42 | 6T | 7E | 9005 |
| * | 0202342 | 2827 | 2 | 7K | 6T | 9101 |
| * | 0202342 | 3497 | 0 | 2A | 5Q | 9208 |
| * | 0202342 | 3497 | 670 | 5Q | 7K | 9205 |
| * | 0202342 | 3540 | 43 | 3R | 5Q | 9306 |
| * | 0202343 | 5630 | 893 | 3T | 3R | 9204 |
| * | 0202345 | 5658 | 1413 | 3R | 7C | 9307 |
| * | 0202346 | 4315 | 1 | 5W | 5W | 9101 |
| * | 0202346 | 4314 | 19 | 5W | 7C | 9008 |
| * | 0202346 | 4799 | 484 | 3Q | 5W | 9206 |
| * | 0202347 | 3610 | 492 | 2N | 7C | 9011 |
| * | 0202347 | 4196 | 586 | 6Q | 2N | 9206 |
| * | 0202348 | 4555 | 96 | 7K | 5D | 9003 |
| * | 0202348 | 5945 | 1390 | 3R | 7K | 9409 |
| * | 0202351 | 5172 | 1097 | 8C | 1G | 9207 |
| * | 0202351 | 6349 | 1177 | 1T | 8C | 9407 |
| * | 0202353 | 5541 | 1062 | 3Q | 7C | 9203 |
| * | 0202353 | 6591 | 1050 | 1G | 3Q | 9402 |
| * | 0202354 | 4883 | 1450 | 1Z | 6F | 9011 |
| * | 0202354 | 5488 | 605 | 8F | 1Z | 9205 |
| * | **0202354** | **6593** | **1105** | **7C** | **1W** | **9408** |
| * | 0202355 | 4491 | 1 | 3Q | 7C | 9005 |
| * | 0202355 | 5522 | 1031 | 7K | 3Q | 9209 |
| * | 0202355 | 5904 | 382 | 1Z | 7C | 9409 |
| * | 0202356 | 4456 | 581 | 3Q | 7C | 8910 |
| * | 0202356 | 4658 | 202 | 1G | 5D | 9004 |
| * | 0202356 | 4973 | 315 | 4D | 6Q | 9201 |
| * | 0202356 | 4973 | 315 | 1Z | 6Q | 9202 |
| * | 0202356 | 5772 | 799 | 3T | 1Z | 9407 |
| * | 0202356 | 5801 | 29 | 3T | 3T | 9501 |
| * | 0202358 | 5207 | 310 | 8P | 7C | 9212 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| | Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|---|
| * | 0202359 | 4736 | 355 | 8C | 7D | 9009 |
| * | 0202359 | 4748 | 12 | 3T | 5D | 9101 |
| * | **0202359** | **6137** | **1389** | **7C** | **3T** | **9404** |
| * | 0202360 | 3352 | 193 | 3W | 1Z | 9001 |
| * | 0202360 | 3546 | 387 | 3P | 1Z | 9006 |
| * | 0202360 | 4101 | 555 | 3R | 3W | 9303 |
| * | 0202361 | 3295 | 484 | 1W | 7C | 9001 |
| * | **0202361** | **4365** | **1070** | **7C** | **7K** | **9207** |
| * | 0202362 | 4576 | 819 | 3Q | 3R | 9208 |
| * | 0202363 | 4001 | 888 | 1Z | 5C | 9004 |
| * | 0202363 | 4280 | 279 | 7K | 1Z | 9012 |
| * | 0202363 | 5024 | 274 | 5Q | 7C | 9209 |
| * | 0202363 | 5610 | 586 | 5C | 3B | 9411 |
| * | 0202364 | 5343 | 1084 | 6J | 2N | 9104 |
| * | 0202364 | 5395 | 52 | 5Q | 7D | 9111 |
| * | 0202364 | 5398 | 55 | 5Q | 7D | 9112 |
| * | 0202365 | 6022 | 745 | 6J | 8C | 9104 |
| * | 0202365 | 6362 | 340 | 6N | 6J | 9203 |
| * | 0202365 | 6385 | 23 | 1A | 3A | 9306 |
| * | 0202366 | 4428 | 56 | 2C | 5D | 9007 |
| * | 0202366 | 4968 | 540 | 5Q | 3Q | 9201 |
| * | 0202367 | 4118 | 46 | 8C | 1Z | 9005 |
| * | 0202367 | 4201 | 83 | 1G | 8C | 9104 |
| * | 0202368 | 3690 | 176 | 5C | 7C | 8910 |
| * | 0202368 | 4447 | 757 | 1W | 5C | 9201 |
| * | **0202368** | **5225** | **778** | **7C** | **3T** | **9409** |
| * | 0202369 | 5314 | 299 | 3Q | 7D | 9303 |
| * | **0202369** | **5323** | **9** | **4D** | **7A** | **9406** |
| * | 0202370 | 4750 | 263 | 6F | 3R | 8911 |
| * | 0202370 | 5368 | 618 | 3T | 6F | 9012 |
| * | **0202370** | **6407** | **1039** | **3W** | **7C** | **9404** |
| * | 0202373 | 3958 | 333 | 1G | 7C | 9003 |
| * | 0202373 | 4975 | 63 | 3T | 7C | 9307 |
| * | 0202373 | 5046 | 71 | 3R | 3T | 9411 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| | Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|---|
| * | 0202374 | 3838 | 1018 | 5Q | 3W | 9108 |
| * | 0202374 | 3870 | 32 | 5Q | 5Q | 9206 |
| * | **0202374** | **4841** | **971** | **3W** | **3B** | **9406** |
| * | 0202375 | 5367 | 806 | 6P | 1Z | 9109 |
| * | 0202375 | 5946 | 579 | 3T | 3T | 9411 |
| * | 0202376 | 5435 | 188 | 8C | 7D | 9205 |
| * | **0202376** | **6017** | **582** | **3W** | **8C** | **9501** |
| * | 0202377 | 4178 | 477 | 3P | 3Q | 9104 |
| * | 0202377 | 4178 | 0 | 7K | 3P | 9107 |
| * | 0202377 | 4469 | 291 | 2S | 1G | 9202 |
| * | **0202377** | **5539** | **1070** | **7C** | **7D** | **9405** |
| * | 0202378 | 4138 | 230 | 3Q | 5Q | 9006 |
| * | 0202378 | 5079 | 941 | 3Q | 3Q | 9210 |
| * | **0202378** | **6199** | **1120** | **7C** | **3B** | **9502** |
| * | 0202379 | 3804 | 1617 | 1C | 3Q | 9006 |
| * | **0202379** | **4584** | **475** | **7C** | **7D** | **9409** |
| * | 0202380 | 4716 | 953 | 1Z | 5D | 9005 |
| * | 0202380 | 5144 | 428 | 8P | 1Z | 9106 |
| * | 0202380 | 5910 | 766 | 6E | 3T | 9412 |
| * | 0202383 | 4488 | 704 | 1Z | 7L | 9003 |
| * | 0202383 | 4497 | 9 | 6F | 1Z | 9104 |
| * | 0202384 | 4630 | 1218 | 2N | 1Z | 9201 |
| * | 0202384 | 4902 | 272 | 7K | 1W | 9211 |
| * | **0202384** | **6239** | **1337** | **7C** | **7C** | **9501** |
| * | 0202385 | 4840 | 786 | 7K | 7D | 9405 |
| * | 0202386 | 4520 | 126 | 1Z | 1Z | 8910 |
| * | 0202386 | 4539 | 19 | 2A | 1Z | 9006 |
| * | 0202386 | 5726 | 1187 | 3B | 4B | 9409 |
| * | 0202388 | 4824 | 638 | 1Z | 7D | 9401 |
| * | 0202390 | 4825 | 347 | 7A | 7C | 9002 |
| * | **0202390** | **5679** | **854** | **7C** | **3D** | **9201** |
| * | 0202391 | 3575 | 417 | 4P | 3Q | 9105 |
| * | 0202391 | 4207 | 632 | 7K | 4A | 9306 |
| * | 0202391 | 4628 | 421 | 5D | 7K | 9408 |
| * | 0202392 | 2619 | 55 | 3R | 1Z | 9003 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202393 | 4800 | 667 | 1Z | 7L | 8911 |
| * 0202393 | 5032 | 232 | 6J | 1Z | 9207 |
| * 0202393 | 5037 | 237 | 3D | 1Z | 9411 |
| * 0202393 | 5040 | 3 | 3D | 3D | 9501 |
| * 0202394 | 3561 | 1063 | 2N | 7C | 9204 |
| * 0202394 | 3800 | 239 | 1Z | 1W | 9309 |
| * 0202397 | 2146 | 215 | 3T | 3Q | 9008 |
| * 0202397 | 3119 | 973 | 3R | 3T | 9312 |
| * 0202398 | 4720 | 1598 | 3R | 7C | 9102 |
| * 0202398 | 4898 | 178 | 5Q | 3R | 9201 |
| * 0202398 | 5212 | 492 | 3R | 3R | 9307 |
| * 0202399 | 3930 | 291 | 6N | 6F | 9003 |
| *** 0202399** | **5106** | **1176** | **7C** | **7C** | **9502** |
| * 0202400 | 5271 | 808 | 6N | 7D | 9310 |
| * 0202401 | 4167 | 305 | 3A | 7D | 8911 |
| * 0202401 | 4803 | 26 | 3P | 7C | 9108 |
| * 0202401 | 4855 | 52 | 3R | 3B | 9203 |
| *** 0202401** | **5842** | **987** | **7C** | **7D** | **9402** |
| * 0202402 | 5027 | 2128 | 1Z | 3Q | 9003 |
| * 0202402 | 5474 | 447 | 8F | 3U | 9207 |
| * 0202402 | 5671 | 197 | 2S | 2N | 9406 |
| * 0202403 | 4299 | 1165 | 3T | 7D | 8911 |
| * 0202403 | 5027 | 728 | 3R | 3Q | 9201 |
| *** 0202403** | **5937** | **910** | **3W** | **3R** | **9410** |
| * 0202404 | 5064 | 509 | 5B | 7C | 9102 |
| * 0202404 | 5107 | 43 | 2N | 5B | 9204 |
| * 0202405 | 3679 | 240 | 2N | 3B | 9210 |
| *** 0202405** | **3768** | **89** | **3W** | **7D** | **9401** |
| * 0202406 | 3635 | 830 | 1Z | 5C | 9108 |
| * 0202406 | 3650 | 15 | 7K | 1Z | 9204 |
| * 0202406 | 4216 | 566 | 1Z | 7K | 9308 |
| * 0202406 | 4430 | 214 | 6F | 1Z | 9406 |
| * 0202407 | 6998 | 273 | 5Q | 7D | 9410 |
| * 0202409 | 5098 | 691 | 8B | 6Q | 9111 |
| * 0202409 | 5845 | 747 | 7L | 8B | 9405 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|
| * 0202410 | 4463 | 1176 | 3A | 3Q | 9003 |
| * 0202410 | 5639 | 3 | 3T | 3B | 9304 |
| *** 0202410** | **5765** | **126** | **3W** | **3T** | **9410** |
| * 0202412 | 4616 | 1613 | 3A | 7K | 9102 |
| *** 0202412** | **5773** | **1157** | **3W** | **3R** | **9407** |
| * 0202413 | 5031 | 523 | 1Z | 7C | 9309 |
| * 0202413 | 5033 | 2 | 3B | 3B | 9312 |
| * 0202415 | 4755 | 435 | 6C | 1Z | 9106 |
| * 0202416 | 4863 | 387 | 6J | 7C | 9501 |
| * 0202417 | 4806 | 1164 | 3A | 7C | 8911 |
| *** 0202417** | **6405** | **1599** | **7C** | **3A** | 9208 |
| * 0202419 | 1873 | 686 | 1W | 7C | 8910 |
| * 0202419 | 1921 | 48 | 1W | 1W | 9001 |
| * 0202419 | 2413 | 492 | 6N | 1W | 9202 |
| * 0202420 | 4405 | 226 | 7K | 5C | 8910 |
| * 0202420 | 4899 | 494 | 6F | 3Q | 9104 |
| *** 0202420** | **5830** | **931** | **7C** | **6F** | **9312** |
| * 0202421 | 4244 | 798 | 5Q | 7D | 9302 |
| *** 0202421** | **4301** | **57** | **3W** | **5Q** | **9401** |
| * 0202423 | 4232 | 1399 | 5C | 6Q | 9011 |
| *** 0202423** | **4393** | **161** | **3W** | **5C** | **9111** |
| * 0202424 | 4268 | 785 | 9C | 7C | 9106 |
| * 0202424 | 4511 | 243 | 1W | 7D | 9201 |
| * 0202424 | 4980 | 469 | 5W | 2N | 9303 |
| * 0202426 | 5476 | 1008 | 3T | 7C | 9108 |
| * 0202426 | 5523 | 47 | 3A | 3T | 9211 |
| * 0202427 | 4540 | 345 | 2N | 1Z | 9102 |
| * 0202427 | 5253 | 13 | 1G | 7C | 9502 |
| * 0202428 | 3119 | 162 | 3Q | 3Q | 9004 |
| * 0202428 | 3635 | 516 | 6Q | 3Q | 9210 |
| * 0202431 | 3949 | 441 | 1G | 5G | 9105 |
| *** 0202431** | **4134** | **185** | **3W** | **1R** | **9111** |
| * 0202432 | 4527 | 1379 | 3Q | 5D | 9104 |
| * 0202432 | 4573 | 46 | 1Z | 5D | 9111 |
| * 0202433 | 3892 | 1157 | 3A | 5Q | 9111 |

# APPENDIX A. FAILURE REMOVALS PLUS RESIDUAL OPERATING TIMES DATA FILTER

| | Engine Serial Number | Flight Hours Since New | Flight Hours Since Last Repair | Reason for Removal | Prior Removal Reason | Start Date |
|---|---|---|---|---|---|---|
| * | 0202437 | 4948 | 313 | 6F | 5D | 9008 |
| * | 0202437 | 5018 | 70 | 3R | 6F | 9102 |
| * | 0202437 | 5398 | 380 | 3R | 3R | 9306 |
| * | 0202438 | 5418 | 1419 | 5W | 5C | 9207 |
| * | **0202438** | **5574** | **156** | **3W** | **2N** | **9407** |
| * | 0202439 | 4403 | 811 | 3Q | 6O | 9001 |
| * | 0202439 | 4552 | 149 | 1Z | 3Q | 9012 |
| * | 0202439 | 5405 | 853 | 6F | 1Z | 9402 |
| * | 0202440 | 4588 | 116 | 4P | 6Q | 9003 |
| * | 0202440 | 5149 | 561 | 7A | 4P | 9202 |
| * | **0202440** | **5892** | **743** | **7C** | **5C** | **9409** |
| * | 0202441 | 4799 | 0 | 5Q | 5G | 8911 |
| * | 0202441 | 5946 | 559 | 1Z | 7C | 9310 |
| * | 0202442 | 5080 | 1279 | 1G | 6Q | 9209 |
| * | 0202443 | 5347 | 1362 | 3A | 5C | 9212 |
| * | 0202443 | 5445 | 98 | 7K | 3R | 9311 |
| * | 0202443 | 5642 | 197 | 7J | 7K | 9406 |
| * | 0202444 | 4656 | 37 | 1Z | 7D | 9009 |
| * | 0202444 | 4660 | 4 | 1Z | 1Z | 9101 |
| * | 0202444 | 5171 | 511 | 5W | 1Z | 9201 |
| * | **0202444** | **6188** | **1017** | **7C** | **5W** | **9311** |

# APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

## A. CONTENTS OF APPENDIX B

Appendix B contains all of the fail times and residual operating times as derived from Appendix A. They are indexed in sequential order. There are 684 true failure times after removing the "zero" entries. There are 106 residual operating times. These are the times used in the Weivull analysis in Chapter II.

# APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

| Index | Fail Times | Index | Fail Times | Index | Fail Times | Index | Fail Times | Index | Fail Times |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 47 | 18 | 93 | 57 | 139 | 113 | 185 | 195 |
| 2 | 1 | 48 | 19 | 94 | 59 | 140 | 114 | 186 | 197 |
| 3 | 1 | 49 | 19 | 95 | 62 | 141 | 115 | 187 | 197 |
| 4 | 1 | 50 | 20 | 96 | 62 | 142 | 115 | 188 | 199 |
| 5 | 1 | 51 | 20 | 97 | 63 | 143 | 116 | 189 | 199 |
| 6 | 2 | 52 | 20 | 98 | 65 | 144 | 116 | 190 | 200 |
| 7 | 2 | 53 | 20 | 99 | 65 | 145 | 116 | 191 | 200 |
| 8 | 2 | 54 | 22 | 100 | 66 | 146 | 117 | 192 | 202 |
| 9 | 2 | 55 | 23 | 101 | 67 | 147 | 120 | 193 | 202 |
| 10 | 2 | 56 | 25 | 102 | 67 | 148 | 122 | 194 | 204 |
| 11 | 2 | 57 | 25 | 103 | 67 | 149 | 126 | 195 | 206 |
| 12 | 2 | 58 | 26 | 104 | 67 | 150 | 129 | 196 | 210 |
| 13 | 2 | 59 | 27 | 105 | 68 | 151 | 130 | 197 | 211 |
| 14 | 3 | 60 | 29 | 106 | 69 | 152 | 138 | 198 | 211 |
| 15 | 3 | 61 | 30 | 107 | 69 | 153 | 140 | 199 | 212 |
| 16 | 3 | 62 | 31 | 108 | 70 | 154 | 143 | 200 | 213 |
| 17 | 3 | 63 | 32 | 109 | 70 | 155 | 143 | 201 | 214 |
| 18 | 3 | 64 | 32 | 110 | 71 | 156 | 149 | 202 | 215 |
| 19 | 3 | 65 | 33 | 111 | 74 | 157 | 149 | 203 | 216 |
| 20 | 3 | 66 | 34 | 112 | 74 | 158 | 151 | 204 | 216 |
| 21 | 3 | 67 | 35 | 113 | 74 | 159 | 154 | 205 | 217 |
| 22 | 3 | 68 | 35 | 114 | 75 | 160 | 154 | 206 | 218 |
| 23 | 4 | 69 | 37 | 115 | 78 | 161 | 155 | 207 | 221 |
| 24 | 4 | 70 | 39 | 116 | 79 | 162 | 157 | 208 | 221 |
| 25 | 4 | 71 | 40 | 117 | 80 | 163 | 160 | 209 | 225 |
| 26 | 5 | 72 | 40 | 118 | 81 | 164 | 161 | 210 | 225 |
| 27 | 5 | 73 | 40 | 119 | 82 | 165 | 162 | 211 | 226 |
| 28 | 6 | 74 | 42 | 120 | 82 | 166 | 163 | 213 | 226 |
| 29 | 7 | 75 | 43 | 121 | 83 | 167 | 168 | 214 | 226 |
| 30 | 7 | 76 | 43 | 122 | 83 | 168 | 168 | 215 | 227 |
| 31 | 9 | 77 | 43 | 123 | 84 | 169 | 169 | 216 | 227 |
| 32 | 10 | 78 | 44 | 124 | 85 | 170 | 170 | 217 | 227 |
| 33 | 11 | 79 | 45 | 125 | 88 | 171 | 172 | 218 | 228 |
| 34 | 11 | 80 | 45 | 126 | 89 | 172 | 176 | 219 | 228 |
| 35 | 11 | 81 | 46 | 127 | 89 | 173 | 178 | 220 | 229 |
| 36 | 11 | 82 | 46 | 128 | 90 | 174 | 178 | 221 | 230 |
| 37 | 11 | 83 | 47 | 129 | 96 | 175 | 178 | 222 | 230 |
| 38 | 12 | 84 | 47 | 130 | 98 | 176 | 179 | 223 | 232 |
| 39 | 13 | 85 | 48 | 131 | 98 | 177 | 183 | 224 | 232 |
| 40 | 14 | 86 | 51 | 132 | 99 | 178 | 188 | 225 | 236 |
| 41 | 15 | 87 | 52 | 133 | 99 | 179 | 189 | 226 | 237 |
| 42 | 15 | 88 | 52 | 134 | 100 | 180 | 189 | 227 | 239 |
| 43 | 15 | 89 | 55 | 135 | 100 | 181 | 190 | 228 | 240 |
| 44 | 15 | 90 | 55 | 136 | 101 | 182 | 192 | 229 | 241 |
| 45 | 15 | 91 | 55 | 137 | 105 | 183 | 193 | 230 | 241 |
| 46 | 16 | 92 | 56 | 138 | 108 | 184 | 194 | 231 | 242 |

# APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

| Index | Fail Times | Index | Fail Times | Index | Fail Times | Index | Fail Times | Index | Fail Times |
|---|---|---|---|---|---|---|---|---|---|
| 232 | 243 | 278 | 315 | 324 | 385 | 370 | 456 | 416 | 527 |
| 233 | 246 | 279 | 320 | 325 | 385 | 371 | 459 | 417 | 528 |
| 234 | 246 | 280 | 320 | 326 | 387 | 372 | 460 | 418 | 529 |
| 235 | 248 | 281 | 322 | 327 | 387 | 373 | 460 | 419 | 529 |
| 236 | 249 | 282 | 323 | 328 | 389 | 374 | 465 | 420 | 530 |
| 237 | 250 | 283 | 326 | 329 | 390 | 375 | 465 | 421 | 533 |
| 238 | 251 | 284 | 326 | 330 | 390 | 376 | 467 | 422 | 538 |
| 239 | 251 | 285 | 327 | 331 | 391 | 377 | 469 | 423 | 540 |
| 240 | 252 | 286 | 332 | 332 | 391 | 378 | 470 | 424 | 553 |
| 241 | 259 | 287 | 333 | 333 | 392 | 379 | 470 | 425 | 555 |
| 242 | 262 | 288 | 333 | 334 | 393 | 380 | 477 | 426 | 555 |
| 243 | 263 | 289 | 333 | 335 | 394 | 381 | 478 | 427 | 557 |
| 244 | 266 | 290 | 335 | 336 | 399 | 382 | 480 | 428 | 557 |
| 245 | 268 | 291 | 337 | 337 | 399 | 383 | 480 | 429 | 559 |
| 246 | 271 | 292 | 337 | 338 | 401 | 384 | 482 | 430 | 560 |
| 247 | 271 | 293 | 338 | 339 | 401 | 385 | 483 | 431 | 561 |
| 248 | 272 | 294 | 338 | 340 | 402 | 386 | 484 | 432 | 563 |
| 249 | 272 | 295 | 339 | 341 | 404 | 387 | 484 | 433 | 566 |
| 250 | 272 | 296 | 340 | 342 | 404 | 388 | 485 | 434 | 567 |
| 251 | 273 | 297 | 340 | 343 | 405 | 389 | 485 | 435 | 567 |
| 252 | 274 | 298 | 345 | 344 | 406 | 390 | 485 | 436 | 570 |
| 253 | 279 | 299 | 346 | 345 | 406 | 391 | 490 | 437 | 573 |
| 254 | 279 | 300 | 347 | 346 | 407 | 392 | 491 | 438 | 577 |
| 255 | 284 | 301 | 347 | 347 | 409 | 393 | 492 | 439 | 579 |
| 256 | 288 | 302 | 354 | 348 | 411 | 394 | 492 | 440 | 579 |
| 257 | 290 | 303 | 355 | 349 | 414 | 395 | 492 | 441 | 580 |
| 258 | 290 | 304 | 355 | 350 | 415 | 396 | 492 | 442 | 581 |
| 259 | 291 | 305 | 355 | 351 | 417 | 397 | 493 | 443 | 586 |
| 260 | 291 | 306 | 356 | 352 | 421 | 398 | 494 | 444 | 586 |
| 261 | 291 | 307 | 357 | 353 | 421 | 399 | 496 | 445 | 592 |
| 262 | 293 | 308 | 358 | 354 | 422 | 400 | 498 | 446 | 595 |
| 263 | 293 | 309 | 361 | 355 | 422 | 401 | 498 | 447 | 596 |
| 264 | 294 | 310 | 362 | 356 | 423 | 402 | 504 | 448 | 596 |
| 265 | 299 | 311 | 362 | 357 | 424 | 403 | 507 | 449 | 600 |
| 266 | 299 | 312 | 365 | 358 | 427 | 404 | 508 | 450 | 601 |
| 267 | 301 | 313 | 368 | 359 | 428 | 405 | 509 | 451 | 605 |
| 268 | 302 | 314 | 371 | 360 | 434 | 406 | 510 | 452 | 609 |
| 269 | 304 | 315 | 373 | 361 | 435 | 407 | 511 | 453 | 611 |
| 270 | 305 | 316 | 376 | 362 | 436 | 408 | 513 | 454 | 614 |
| 271 | 306 | 317 | 380 | 363 | 436 | 409 | 516 | 455 | 615 |
| 272 | 309 | 318 | 380 | 364 | 438 | 410 | 516 | 456 | 615 |
| 273 | 310 | 319 | 381 | 365 | 439 | 411 | 517 | 457 | 616 |
| 274 | 310 | 320 | 382 | 366 | 441 | 412 | 518 | 458 | 618 |
| 275 | 313 | 321 | 382 | 367 | 447 | 413 | 521 | 459 | 618 |
| 276 | 314 | 322 | 384 | 368 | 448 | 414 | 523 | 460 | 632 |
| 277 | 315 | 323 | 384 | 369 | 450 | 415 | 524 | 461 | 635 |

# APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

| Index | Fail Times |
|---|---|
| 462 | 638 |
| 463 | 640 |
| 464 | 648 |
| 465 | 652 |
| 466 | 653 |
| 467 | 656 |
| 468 | 659 |
| 469 | 660 |
| 470 | 661 |
| 471 | 662 |
| 472 | 667 |
| 473 | 667 |
| 474 | 668 |
| 475 | 670 |
| 476 | 679 |
| 477 | 681 |
| 478 | 685 |
| 479 | 686 |
| 480 | 688 |
| 481 | 688 |
| 482 | 691 |
| 483 | 691 |
| 484 | 692 |
| 485 | 696 |
| 486 | 698 |
| 487 | 699 |
| 488 | 703 |
| 489 | 704 |
| 490 | 704 |
| 491 | 722 |
| 492 | 724 |
| 493 | 727 |
| 494 | 728 |
| 495 | 731 |
| 496 | 733 |
| 497 | 738 |
| 498 | 738 |
| 499 | 745 |
| 500 | 747 |
| 501 | 747 |
| 502 | 747 |
| 503 | 757 |
| 504 | 761 |
| 505 | 761 |
| 506 | 766 |
| 507 | 770 |

| Index | Fail Times |
|---|---|
| 508 | 771 |
| 509 | 778 |
| 510 | 785 |
| 511 | 785 |
| 512 | 786 |
| 513 | 790 |
| 514 | 791 |
| 515 | 798 |
| 516 | 799 |
| 517 | 800 |
| 518 | 802 |
| 519 | 804 |
| 520 | 806 |
| 521 | 808 |
| 522 | 809 |
| 523 | 811 |
| 524 | 814 |
| 525 | 816 |
| 526 | 817 |
| 527 | 819 |
| 528 | 822 |
| 529 | 830 |
| 530 | 832 |
| 531 | 840 |
| 532 | 843 |
| 533 | 850 |
| 534 | 852 |
| 535 | 853 |
| 536 | 859 |
| 537 | 860 |
| 538 | 860 |
| 539 | 862 |
| 540 | 864 |
| 541 | 865 |
| 542 | 879 |
| 543 | 882 |
| 544 | 883 |
| 545 | 886 |
| 546 | 887 |
| 547 | 888 |
| 548 | 892 |
| 549 | 893 |
| 550 | 896 |
| 551 | 896 |
| 552 | 902 |
| 553 | 912 |

| Index | Fail Times |
|---|---|
| 554 | 914 |
| 555 | 916 |
| 556 | 918 |
| 557 | 921 |
| 558 | 925 |
| 559 | 927 |
| 560 | 930 |
| 561 | 934 |
| 562 | 937 |
| 563 | 939 |
| 564 | 941 |
| 565 | 942 |
| 566 | 946 |
| 567 | 953 |
| 568 | 954 |
| 569 | 957 |
| 570 | 958 |
| 571 | 959 |
| 572 | 960 |
| 573 | 973 |
| 574 | 975 |
| 575 | 988 |
| 576 | 989 |
| 577 | 994 |
| 578 | 995 |
| 579 | 998 |
| 580 | 998 |
| 581 | 998 |
| 582 | 1006 |
| 583 | 1007 |
| 584 | 1007 |
| 585 | 1008 |
| 586 | 1011 |
| 587 | 1015 |
| 588 | 1018 |
| 589 | 1018 |
| 590 | 1026 |
| 591 | 1030 |
| 592 | 1030 |
| 593 | 1031 |
| 594 | 1042 |
| 595 | 1050 |
| 596 | 1056 |
| 597 | 1062 |
| 598 | 1062 |
| 599 | 1063 |

| Index | Fail Times |
|---|---|
| 600 | 1066 |
| 601 | 1084 |
| 602 | 1089 |
| 603 | 1092 |
| 604 | 1096 |
| 605 | 1097 |
| 606 | 1100 |
| 607 | 1103 |
| 608 | 1105 |
| 609 | 1107 |
| 610 | 1115 |
| 611 | 1115 |
| 612 | 1116 |
| 613 | 1121 |
| 614 | 1126 |
| 615 | 1128 |
| 616 | 1135 |
| 617 | 1148 |
| 618 | 1149 |
| 619 | 1150 |
| 620 | 1152 |
| 621 | 1153 |
| 622 | 1157 |
| 623 | 1157 |
| 624 | 1164 |
| 625 | 1165 |
| 626 | 1170 |
| 627 | 1175 |
| 628 | 1176 |
| 629 | 1177 |
| 630 | 1179 |
| 631 | 1183 |
| 632 | 1187 |
| 633 | 1198 |
| 634 | 1199 |
| 635 | 1212 |
| 636 | 1212 |
| 637 | 1218 |
| 638 | 1235 |
| 639 | 1242 |
| 640 | 1249 |
| 641 | 1275 |
| 642 | 1279 |
| 643 | 1282 |
| 644 | 1283 |
| 645 | 1285 |

| Index | Fail Times |
|---|---|
| 646 | 1291 |
| 647 | 1316 |
| 648 | 1320 |
| 649 | 1327 |
| 650 | 1336 |
| 651 | 1350 |
| 652 | 1353 |
| 653 | 1354 |
| 654 | 1360 |
| 655 | 1362 |
| 656 | 1370 |
| 657 | 1370 |
| 658 | 1373 |
| 659 | 1379 |
| 660 | 1389 |
| 661 | 1390 |
| 662 | 1399 |
| 663 | 1413 |
| 664 | 1419 |
| 665 | 1423 |
| 666 | 1430 |
| 667 | 1441 |
| 668 | 1443 |
| 669 | 1447 |
| 670 | 1450 |
| 671 | 1456 |
| 672 | 1470 |
| 673 | 1482 |
| 674 | 1490 |
| 675 | 1497 |
| 676 | 1513 |
| 677 | 1514 |
| 678 | 1555 |
| 679 | 1598 |
| 680 | 1613 |
| 681 | 1617 |
| 682 | 1638 |
| 683 | 1932 |
| 684 | 2128 |

# APPENDIX B. INDEXED FAIL TIMES AND RESIDUAL OPERATING TIMES

| Index | Residual Op Times | Index | Residual Op Times | Index | Residual Op Times |
|---|---|---|---|---|---|
| 1 | 3 | 46 | 586 | 91 | 1120 |
| 2 | 5 | 47 | 592 | 92 | 1157 |
| 3 | 9 | 48 | 599 | 93 | 1176 |
| 4 | 14 | 49 | 599 | 94 | 1221 |
| 5 | 23 | 50 | 618 | 95 | 1247 |
| 6 | 25 | 51 | 618 | 96 | 1249 |
| 7 | 26 | 52 | 625 | 97 | 1251 |
| 8 | 30 | 53 | 630 | 98 | 1337 |
| 9 | 31 | 54 | 650 | 99 | 1389 |
| 10 | 49 | 55 | 658 | 100 | 1474 |
| 11 | 57 | 56 | 684 | 101 | 1503 |
| 12 | 89 | 57 | 692 | 102 | 1534 |
| 13 | 99 | 58 | 703 | 103 | 1585 |
| 14 | 106 | 59 | 723 | 104 | 1599 |
| 15 | 126 | 60 | 730 | 105 | 1740 |
| 16 | 156 | 61 | 741 | 106 | 2383 |
| 17 | 156 | 62 | 743 | | |
| 18 | 161 | 63 | 748 | | |
| 19 | 166 | 64 | 750 | | |
| 20 | 174 | 65 | 764 | | |
| 21 | 185 | 66 | 771 | | |
| 22 | 205 | 67 | 778 | | |
| 23 | 230 | 68 | 779 | | |
| 24 | 270 | 69 | 814 | | |
| 25 | 280 | 70 | 830 | | |
| 26 | 323 | 71 | 849 | | |
| 27 | 341 | 72 | 854 | | |
| 28 | 352 | 73 | 874 | | |
| 29 | 382 | 74 | 910 | | |
| 30 | 382 | 75 | 931 | | |
| 31 | 386 | 76 | 946 | | |
| 32 | 391 | 77 | 971 | | |
| 33 | 396 | 78 | 985 | | |
| 34 | 434 | 79 | 987 | | |
| 35 | 458 | 80 | 1017 | | |
| 36 | 475 | 81 | 1022 | | |
| 37 | 483 | 82 | 1039 | | |
| 38 | 503 | 83 | 1051 | | |
| 39 | 518 | 84 | 1067 | | |
| 40 | 534 | 85 | 1069 | | |
| 41 | 553 | 86 | 1070 | | |
| 42 | 554 | 87 | 1070 | | |
| 43 | 570 | 88 | 1072 | | |
| 44 | 582 | 89 | 1105 | | |
| 45 | 584 | 90 | 1112 | | |

# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

## A. CONTENTS OF APPENDIX C

Appendix C contains 10 Mathcad graphical solution printouts showing the behavior of the two curves f(x) and g(x) from a macro-view for different combinations of input cost "u", cost ratio pairs, parameter values, and component HT. This appendix compliments the discussion in Chapter 4 about Mathcad graphical solution sensitivity and can be used as a tool to estimate the confidence limits of the solution for x.

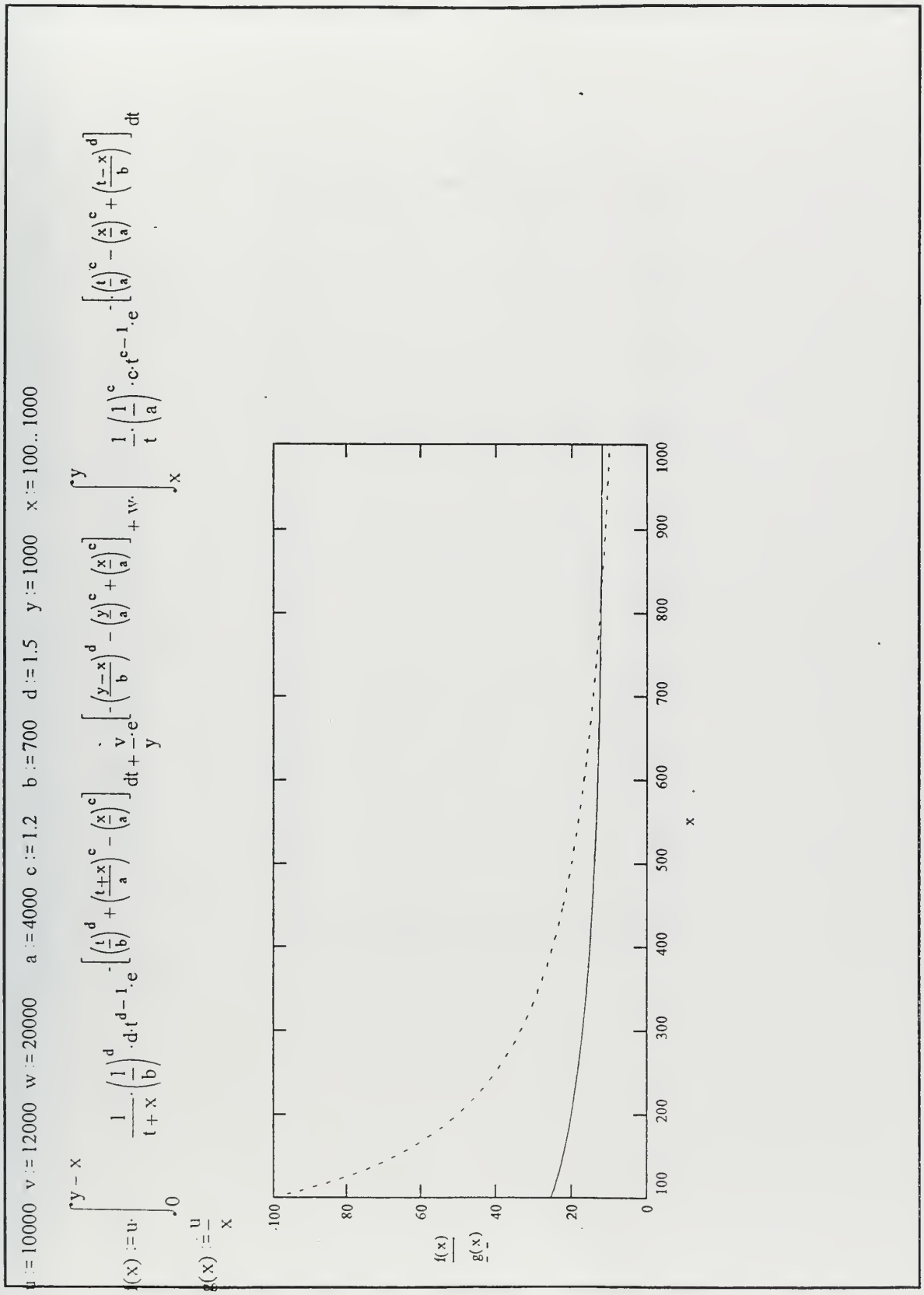
# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000$ $v := 11000$ $w := 20000$ $a := 4000$ $c := 1.2$ $b := 700$ $d := 1.5$ $y := 1000$ $x := 100 .. 1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{t}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{t}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$

# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

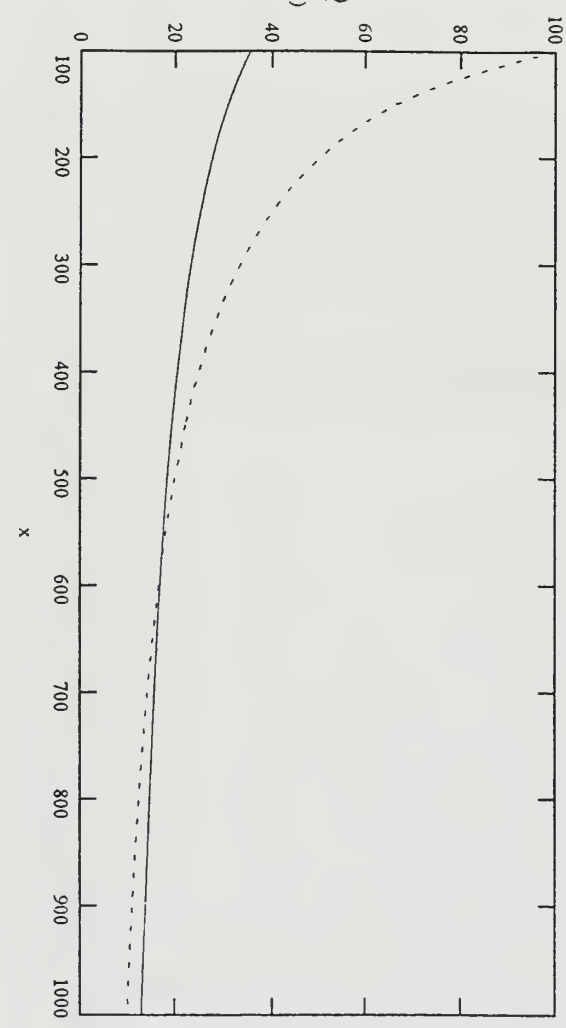

u := 10000 v := 12000 w := 20000 a := 4000 c := 1.2 b := 700 d := 1.5 y := 1000 x := 100 .. 1000
f(x) := u · ∫ from 0 to y-x of 1/(t+x) · (1/b)^d · d · t^(d-1) · e^(-[(t/b)^d + ((t+x)/a)^c - (x/a)^c]) dt + v/y · e^(-[((y-x)/b)^d - (y/a)^c + (x/a)^c]) + w · ∫ from x to y of 1/t · (1/a)^c · c · t^(c-1) · e^(-[(t/a)^c - (x/a)^c + ((t-x)/b)^d]) dt
g(x) := u/x
f(x)/g(x)
x
100
80
60
40
20
0
100
200
300
400
500
600
700
800
900
1000

# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000$ $v := 13000$ $w := 30000$ $a := 2000$ $c := 1.2$ $b := 700$ $d := 2.0$ $y := 1000$ $x := 100 .. 1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$

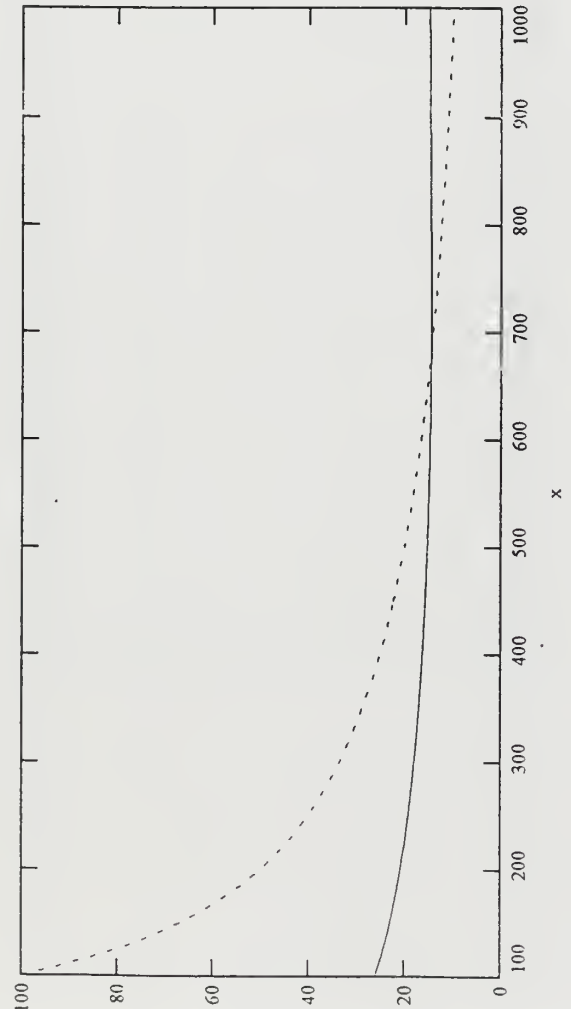


# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 15000 \quad w := 20000 \quad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100 .. 1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$



# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 30000 \quad w := 80000 \quad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100 .. 1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

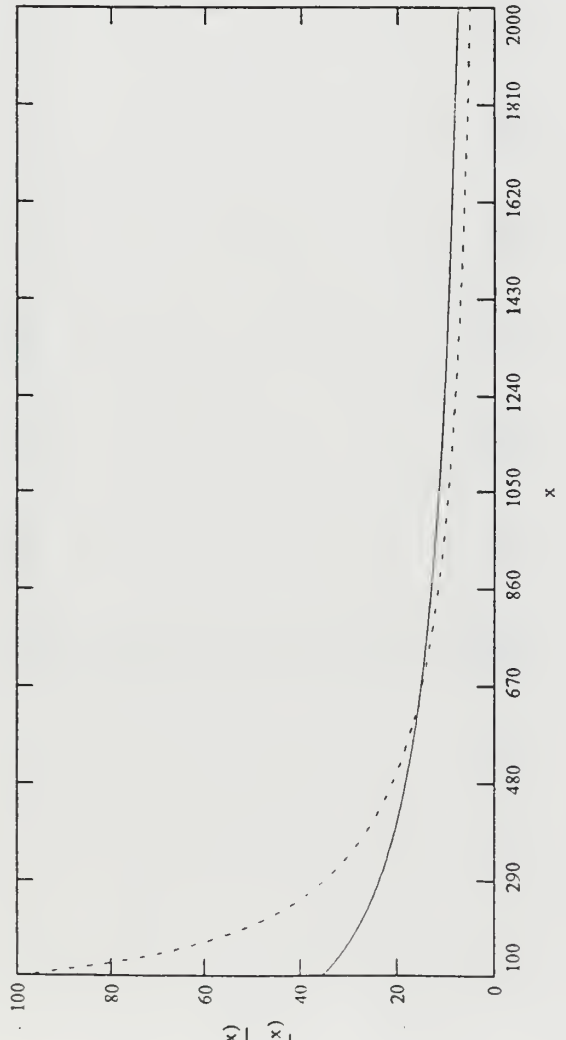
$$g(x) := \frac{u}{x}$$

# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 15000 \quad w := 30000 \quad a := 2000 \quad c := 1.2 \quad b := 1000 \quad d := 1.5 \quad y := 2000 \quad x := 100..2000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$



# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 10000 \quad w := 10000 \quad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100 .. 1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

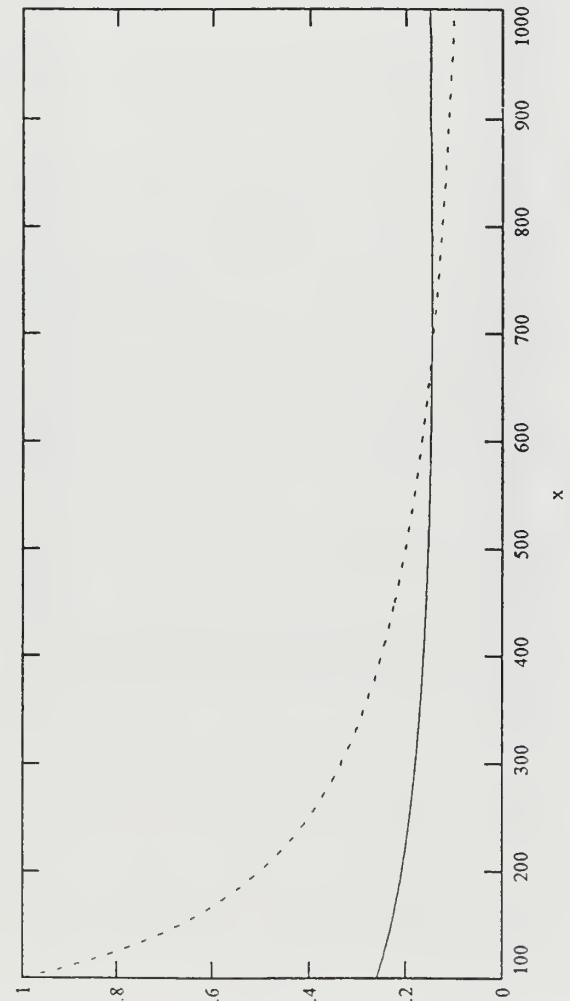
$$g(x) := \frac{u}{x}$$

# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 100 \quad v := 150 \quad w := 200 \quad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 1.5 \quad y := 1000 \quad x := 100..1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$



# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000$ $v := 11000$ $w := 12000$ $a := 4000$ $c := 1.2$ $b := 700$ $d := 1.5$ $y := 1000$ $x := 100..1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{\left[-\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

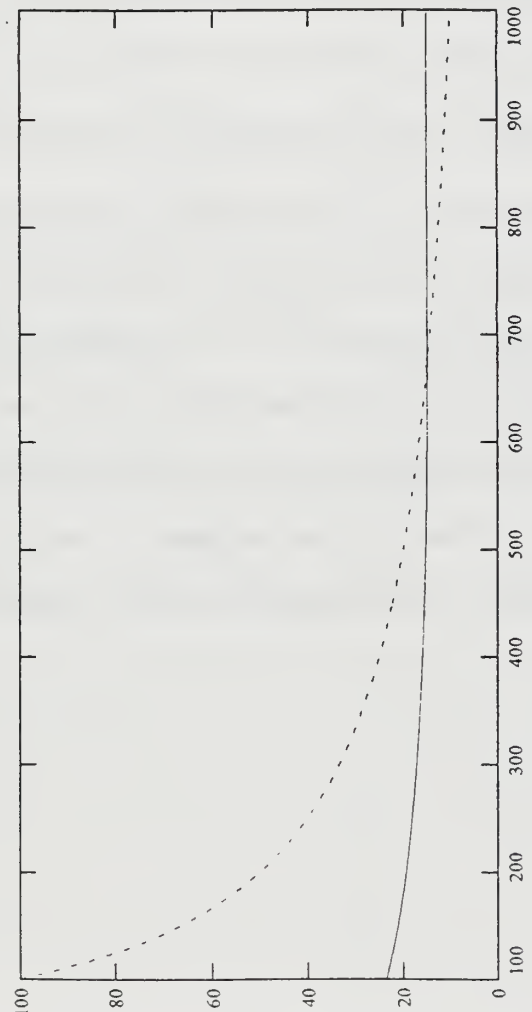
$$g(x) := \frac{u}{x}$$

# APPENDIX C. MATHCAD GRAPHICAL SOLUTION PRINTOUTS

$u := 10000 \quad v := 15000 \quad w := 20000 \quad a := 4000 \quad c := 1.2 \quad b := 700 \quad d := 2.0 \quad y := 1000 \quad x := 100 .. 1000$

$$f(x) := u \cdot \int_0^{y-x} \frac{1}{t+x} \cdot \left(\frac{1}{b}\right)^d \cdot d \cdot t^{d-1} \cdot e^{-\left[\left(\frac{t}{b}\right)^d + \left(\frac{t+x}{a}\right)^c - \left(\frac{x}{a}\right)^c\right]} dt + \frac{v}{y} \cdot e^{-\left[\left(\frac{y-x}{b}\right)^d - \left(\frac{y}{a}\right)^c + \left(\frac{x}{a}\right)^c\right]} + w \cdot \int_x^y \frac{1}{t} \cdot \left(\frac{1}{a}\right)^c \cdot c \cdot t^{c-1} \cdot e^{-\left[\left(\frac{t}{a}\right)^c - \left(\frac{x}{a}\right)^c + \left(\frac{t-x}{b}\right)^d\right]} dt$$

$$g(x) := \frac{u}{x}$$



# APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

## A. CONTENTS OF APPENDIX D

Appendix D is a tabulation of solutions for optimal NBT "x" for 26 different combinations of cost ratio pairs, engine/component Weibull parameters, and component HT. Each box is a separate combination, and each parameter and HT combination was inputted for the same range of cost ratios as shown in the matrix on the right of each box. The input values for the Weibull parameter and component HT are shown in bold.

For example, the first scenario on page 88 shows bolded values of 2000, 1.0, 500, 1.2, and 1000 for $\theta$ component, $\beta$ component, $\theta$ engine, $\beta$ engine and component HT, respectively. The corresponding solution for "x" for these input values, from the optimizing equation for NBT in Mathcad, are tabulated to the right for each cost ratio pair. For a cost ratio pair (Ci/Cn, Cf/Cn) = (1.1, 1.2) the solution for "x" is 910. This means that for a component with a HT of 1000 and the given combination of parameters the accumulated number of operating hours when the component should be inspected when the engine has failed is 910 hours. Inspecting the component on a failed engine any time before this is not cost effective. For a cost ratio pair of (1.5, 2) the solution for "x" is 670, and so on.

# APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 910 | 895 | 865 | 720 | 260 | 168 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 710 | 670 | 560 | 250 | 165 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 484 | 240 | 160 |
| | | | | | 3 | | | | | 226 | 155 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 145 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | 2000 | **4000** | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | 1.0 | **1.2** | 1.5 | | 1.1 | 912 | 908 | 897 | 870 | 675 | 500 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 720 | 705 | 670 | 535 | 435 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 567 | 464 | 390 |
| | | | | | 3 | | | | | 390 | 340 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 265 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | 2000 | 4000 | **6000** | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | 1.0 | 1.2 | **1.5** | | 1.1 | 915 | 912 | 908 | 900 | 863 | 825 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 728 | 720 | 710 | 663 | 630 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 598 | 563 | 535 |
| | | | | | 3 | | | | | 461 | 441 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 525 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | 2000 | **4000** | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 912 | 907 | 895 | 863 | 600 | 405 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 720 | 703 | 660 | 485 | 365 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 560 | 425 | 335 |
| | | | | | 3 | | | | | 360 | 297 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 236 |

# APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

| Parameter | Parameter Values | | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | 2000 | 4000 | **6000** | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 915 | 910 | 930 | 885 | 780 | 640 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 725 | 715 | 685 | 588 | 505 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 580 | 500 | 436 |
| | | | | | 3 | | | | | 413 | 368 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 277 |

| Parameter | Parameter Values | | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | 1.0 | **1.2** | 1.5 | | 1.1 | 910 | 893 | 860 | 720 | 300 | 205 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 710 | 670 | 565 | 285 | 200 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 492 | 273 | 196 |
| | | | | | 3 | | | | | 254 | 187 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 170 |

| Parameter | Parameter Values | | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | 1.0 | 1.2 | **1.5** | | 1.1 | 910 | 895 | 863 | 735 | 358 | 260 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 710 | 673 | 580 | 340 | 255 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 507 | 320 | 245 |
| | | | | | 3 | | | | | 294 | 234 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 205 |

| Parameter | Parameter Values | | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 910 | 890 | 855 | 700 | 240 | 155 |
| θ Engine (b) | 500 | **700** | 1000 | Ci/Cn | 1.5 | | 685 | 640 | 525 | 230 | 150 |
| β Engine (d) | 1.2 | **1.5** | 2.0 | | 2 | | | | 445 | 218 | 145 |
| | | | | | 3 | | | | | 200 | 140 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 125 |

# APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 904 | 888 | 850 | 685 | 225 | 140 |
| θ Engine (b) | 500 | 700 | **1000** | Ci/Cn | 1.5 | | 660 | 610 | 490 | 210 | 135 |
| β Engine (d) | 1.2 | 1.5 | **2.0** | | 2 | | | | 402 | 195 | 130 |
| | | | | | 3 | | | | | 175 | 122 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 105 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 908 | 895 | 860 | 710 | 245 | 155 |
| θ Engine (b) | 500 | **700** | 1000 | Ci/Cn | 1.5 | | 690 | 645 | 530 | 235 | 153 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 448 | 220 | 147 |
| | | | | | 3 | | | | | 200 | 140 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 124 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 907 | 893 | 855 | 695 | 240 | 145 |
| θ Engine (b) | 500 | 700 | **1000** | Ci/Cn | 1.5 | | 675 | 627 | 510 | 220 | 140 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 420 | 202 | 135 |
| | | | | | 3 | | | | | 182 | 128 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 110 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 910 | 895 | 860 | 715 | 260 | 165 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 703 | 665 | 560 | 250 | 163 |
| β Engine (d) | 1.2 | **1.5** | 2.0 | | 2 | | | | 487 | 243 | 160 |
| | | | | | 3 | | | | | 230 | 158 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | 147 |

# APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

| Parameter | Parameter Values | | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 905 | 890 | 860 | 710 | 260 | 165 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 695 | 660 | 560 | 250 | 163 |
| β Engine (d) | 1.2 | 1.5 | **2.0** | | 2 | | | | 492 | 245 | 160 |
| | | | | | 3 | | | | | 237 | 154 |
| Component HT (y) | **1000** | | 2000 | | 6 | | | | | | |

| Parameter | Parameter Values | | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 1820 | 1765 | 1545 | 820 | 258 | 165 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 1498 | 1305 | 795 | 258 | 165 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 775 | 258 | 165 |
| | | | | | 3 | | | | | 258 | 165 |
| Component HT (y) | 1000 | | **2000** | | 6 | | | | | | 165 |

| Parameter | Parameter Values | | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | 2000 | **4000** | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | 1.0 | **1.2** | 1.5 | | 1.1 | 1835 | 1815 | 1760 | 1520 | 700 | 488 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 1520 | 1460 | 1288 | 685 | 485 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 1175 | 675 | 482 |
| | | | | | 3 | | | | | 657 | 477 |
| Component HT (y) | 1000 | | **2000** | | 6 | | | | | | 466 |

| Parameter | Parameter Values | | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | 2000 | 4000 | **6000** | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | 1.0 | 1.2 | **1.5** | | 1.1 | 1840 | 1830 | 1805 | 1740 | 1300 | 1010 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 1540 | 1510 | 1450 | 1170 | 965 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 1300 | 1085 | 925 |
| | | | | | 3 | | | | | 990 | 870 |
| Component HT (y) | 1000 | | **2000** | | 6 | | | | | | 780 |

# APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

| Parameter | Parameter Values | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cf/Cn | | | | | |
| θ Component (a) | 2000 | **4000** | 6000 | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | 1.1 | 1830 | 1810 | 1760 | 1530 | 610 | 400 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn 1.5 | | 1520 | 1460 | 1280 | 600 | 400 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | 2 | | | | 1165 | 596 | 398 |
| | | | | 3 | | | | | 583 | 395 |
| Component HT (y) | 1000 | | **2000** | 6 | | | | | | 386 |

| Parameter | Parameter Values | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cf/Cn | | | | | |
| θ Component (a) | 2000 | 4000 | **6000** | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | 1.1 | 1835 | 1825 | 1795 | 1700 | 985 | 660 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn 1.5 | | 1533 | 1500 | 1400 | 930 | 645 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | 2 | | | | 1262 | 885 | 640 |
| | | | | 3 | | | | | 830 | 616 |
| Component HT (y) | 1000 | | **2000** | 6 | | | | | | 585 |

| Parameter | Parameter Values | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | 1.0 | **1.2** | 1.5 | 1.1 | 1820 | 1740 | 1425 | 775 | 292 | 201 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn 1.5 | | 1460 | 1250 | 760 | 292 | 201 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | 2 | | | | 750 | 292 | 201 |
| | | | | 3 | | | | | 292 | 201 |
| Component HT (y) | 1000 | | **2000** | 6 | | | | | | 201 |

| Parameter | Parameter Values | | | | Solution Values for "x" | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | 1.0 | 1.2 | **1.5** | 1.1 | 1810 | 1700 | 1300 | 758 | 345 | 255 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn 1.5 | | 1440 | 1195 | 750 | 345 | 255 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | 2 | | | | 740 | 345 | 255 |
| | | | | 3 | | | | | 345 | 255 |
| Component HT (y) | **1000** | | 2000 | 6 | | | | | | 255 |

# APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 1810 | 1740 | 1485 | 750 | 230 | 148 |
| θ Engine (b) | 500 | **700** | 1000 | Ci/Cn | 1.5 | | 1415 | 1230 | 750 | 230 | 148 |
| β Engine (d) | 1.2 | **1.5** | 2.0 | | 2 | | | | 750 | 230 | 148 |
| | | | | | 3 | | | | | 230 | 148 |
| Component HT (y) | 1000 | | **2000** | | 6 | | | | | | 148 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 1800 | 1720 | 1435 | 705 | 210 | 132 |
| θ Engine (b) | 500 | 700 | **1000** | Ci/Cn | 1.5 | | 1343 | 1150 | 675 | 210 | 132 |
| β Engine (d) | 1.2 | 1.5 | **2.0** | | 2 | | | | 655 | 210 | 132 |
| | | | | | 3 | | | | | 210 | 132 |
| Component HT (y) | 1000 | | **2000** | | 6 | | | | | | 132 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 1815 | 1750 | 1500 | 758 | 235 | 150 |
| θ Engine (b) | 500 | **700** | 1000 | Ci/Cn | 1.5 | | 1415 | 1225 | 730 | 235 | 150 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 705 | 235 | 150 |
| | | | | | 3 | | | | | 235 | 150 |
| Component HT (y) | 1000 | | **2000** | | 6 | | | | | | 150 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 1810 | 1735 | 1460 | 715 | 215 | 137 |
| θ Engine (b) | 500 | 700 | **1000** | Ci/Cn | 1.5 | | 1365 | 1160 | 675 | 214 | 137 |
| β Engine (d) | **1.2** | 1.5 | 2.0 | | 2 | | | | 640 | 213 | 137 |
| | | | | | 3 | | | | | 210 | 137 |
| Component HT (y) | 1000 | | **2000** | | 6 | | | | | | 137 |

# APPENDIX D. OPTIMAL NBT EQUATION SENSITIVITY ANALYSIS SOLUTIONS

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 1805 | 1755 | 1530 | 795 | 255 | 163 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 1480 | 1320 | 790 | 255 | 163 |
| β Engine (d) | 1.2 | **1.5** | 2.0 | | 2 | | | | 785 | 255 | 163 |
| | | | | | 3 | | | | | 255 | 163 |
| Component HT (y) | 1000 | | **2000** | | 6 | | | | | | 163 |

| Parameter | Parameter Values | | | Solution Values for "x" | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cf/Cn | | | | | |
| θ Component (a) | **2000** | 4000 | 6000 | | | 1.2 | 1.5 | 2 | 3 | 6 | 8 |
| β Component (c) | **1.0** | 1.2 | 1.5 | | 1.1 | 1810 | 1750 | 1530 | 800 | 255 | 165 |
| θ Engine (b) | **500** | 700 | 1000 | Ci/Cn | 1.5 | | 1495 | 1355 | 800 | 255 | 165 |
| β Engine (d) | 1.2 | 1.5 | **2.0** | | 2 | | | | 800 | 255 | 165 |
| | | | | | 3 | | | | | 255 | 165 |
| Component HT (y) | 1000 | | **2000** | | 6 | | | | | | 165 |

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